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SOURCE STUDIES IN THE NEAR AND FAR FIELD

Lawrence S. Turnbull, et al

Texas Instruments, Incorporated

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## 20. Continued

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**SEMI-ANNUAL TECHNICAL REPORT NO. 3 - PART A**

**1 MAY 1974 TO 31 OCTOBER 1974**

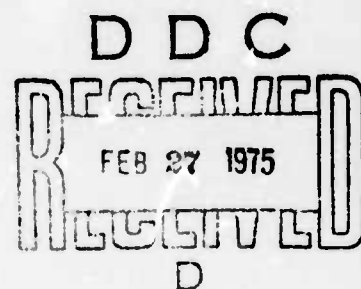
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## ABSTRACT

A program has been undertaken to examine the seismic source in the near- and far-fields. Near field accelerogram spectra have been analyzed for corner frequency, seismic moment, and stress drop. For the Bear Valley earthquake of June 22, 1973, a stress drop ( $\Delta\sigma$ ) of 300 bars was obtained using Brune's source theory. Our data sample, though, was insufficient to determine any empirical relationship between corner frequency and local magnitude and its association with stress drop.

In our examination of far-field source spectral characteristics, de-multipathing procedures have been implemented on the PDP-15 interactive graphics system. Three-dimensional computer plots of double couple source spectra have been produced, and are being used in an exhaustive analysis of far-field spectral characteristics as a function of source configuration. Finally, we briefly examined two discriminants,  $LQ/LR$  and  $M_s - m_b$ . For a double couple source,  $LQ/LR$  amplitudes at 30 seconds period were found to be greater than 1 for depths of 5, 30, and 50 kilometers. The second discriminant,  $M_s - m_b$ , was studied with the objective of reducing the scatter of the earthquake population by minimizing the affect of the source mechanism radiation pattern and by obtaining the  $M_s$  value at the same period for all events and all components. Neither of these approaches reduced the scatter.

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## SECTION I

### ANALYSIS OF NEAR FIELD DATA

#### A. INTRODUCTION

In our past studies of near field data (Turnbull and Battis, 1974), several events have been analyzed using the Haskell's (1969) moving dislocation source to fit waveforms in the time domain. Software has also been developed for a Cagnaird dislocation source, and it is now being applied to these previously analyzed events. For the past several months, though, we have examined the spectra of these events in an attempt to infer source characteristics. In Subsection B, a brief description of the method of analysis is given. The results of the spectral analysis is given in Subsection C. Finally, in Subsection D, these results are summarized and the direction of our future research is given.

#### B. METHOD OF ANALYSIS

To obtain the spectra required for this investigation, the FORTRAN program CORPLT was written. Using accelerogram data placed on tapes in a standardized format (Tsai and Patton, 1972), this program initially decimates and determines a baseline. A high pass filter is then applied and the autocorrelation of the accelerogram is calculated. A (cosine)<sup>N</sup> taper is applied to this autocorrelation function which in turn acts as a low pass filter. The acceleration amplitude spectrum is then calculated by Fourier analysis of the autocorrelation spectrum. Two sequential divisions of the acceleration amplitude spectrum by  $2\pi f$  provide the velocity and displacement amplitude spectrum, and the normalized energy density spectra of each

are plotted. In addition, an option to enable comparison of spectra, such as signal-to-noise spectrum, is available.

Once the spectra is obtained, the corner frequency ( $f_0$ ) and the low frequency levels ( $\Omega_0$ ) were evaluated. An attempt was made to pick these values in a consistent manner. The corner frequency was chosen as the absolute peak amplitude of the velocity spectrum which lies at a higher frequency than the first local minima above the high-pass filter cut off frequency. From the displacement spectrum, a value was obtained for the low frequency spectral level. This was accomplished by determining an average spectral value from ten frequency values preceeding the corner frequency (never going below the high-pass filter corner frequency). The results of these evaluations are given in the following paragraphs.

### C. ANALYSIS OF NEAR FIELD SPECTRA

An example of the spectra obtained from the program CORPLT is shown in Figures I-1a, I-1b, and I-1c, where the acceleration, velocity, and displacement spectra are shown, respectively, of the signal and noise of the Bear Valley earthquake of June 22, 1973. The ratio of the signal plus noise amplitude to the noise amplitude at the corner frequency (from the displacement spectrum) for this event is approximately 12 (the cut off of the high-pass filter occurs at 0.6 Hz). The results of the analysis of this spectra is given in Table I-1, along with the analysis of several other events.

Thirty-five accelerograms from eighteen different earthquakes have been analyzed. Thirty-one of these records were compiled by the Earthquake Engineering Research Laboratory of the California Institute of Technology. These events are mostly large magnitude with a local magnitude ( $M_L$ ) in the range from 4.5 to 7.7. Five of the seventeen events compiled by Cal Tech were recorded at more than one station. The remaining twelve events include six events of the San Fernando aftershock series recorded only at

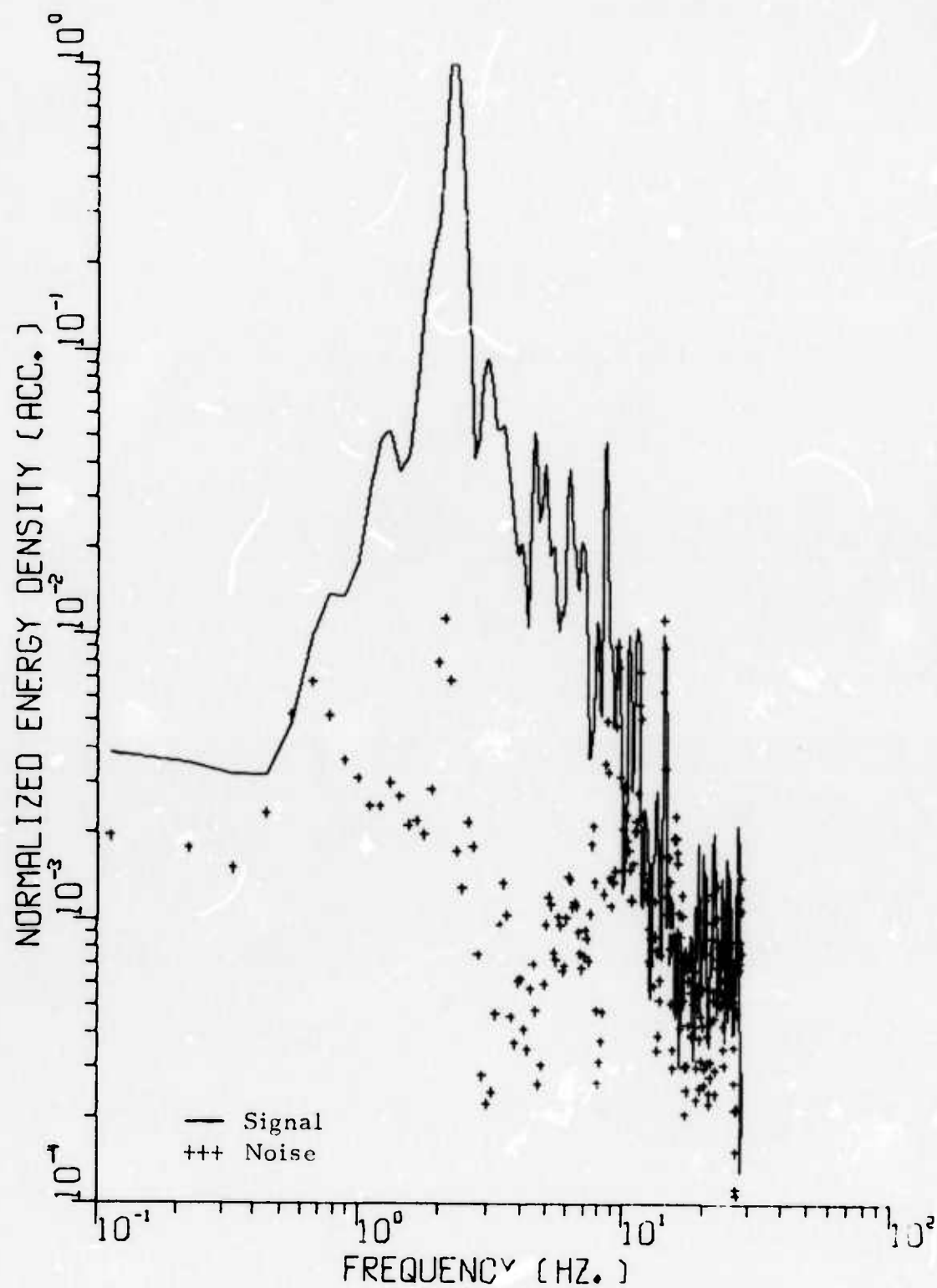


FIGURE I-1a

THE NORMALIZED ENERGY DENSITY ACCELERATION SPECTRUM  
OF THE SIGNAL AND NOISE FOR THE BEAR VALLEY  
EARTHQUAKE OF JUNE 22, 1973 RECORDED AT  
SITE 8 (N45E COMPONENT)

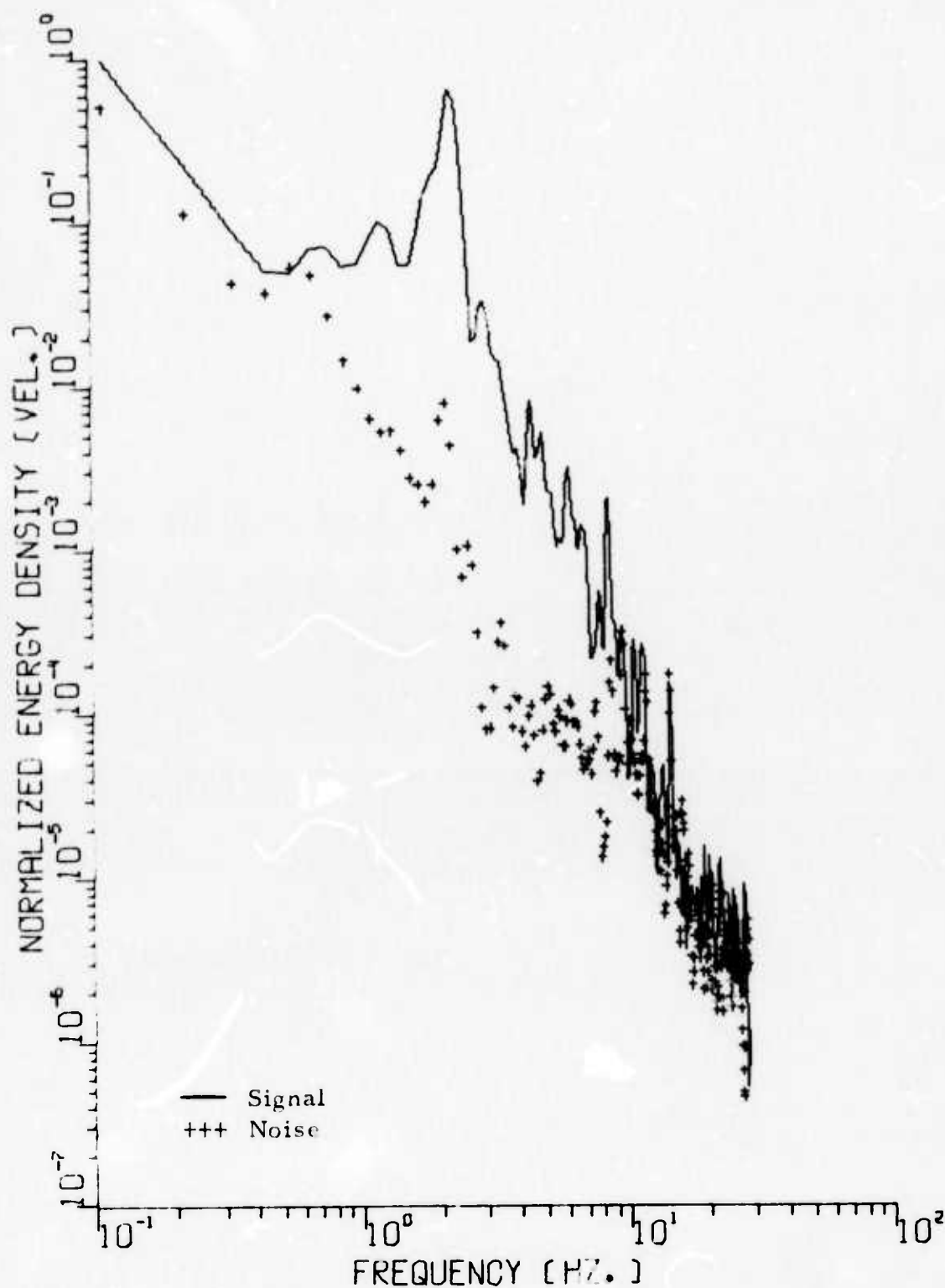


FIGURE I-1b

THE NORMALIZED ENERGY DENSITY VELOCITY SPECTRUM OF THE  
SIGNAL AND NOISE FOR THE BEAR VALLEY EARTHQUAKE OF  
JUNE 22, 1973 RECORDED AT SITE 8 (N45E COMPONENT)

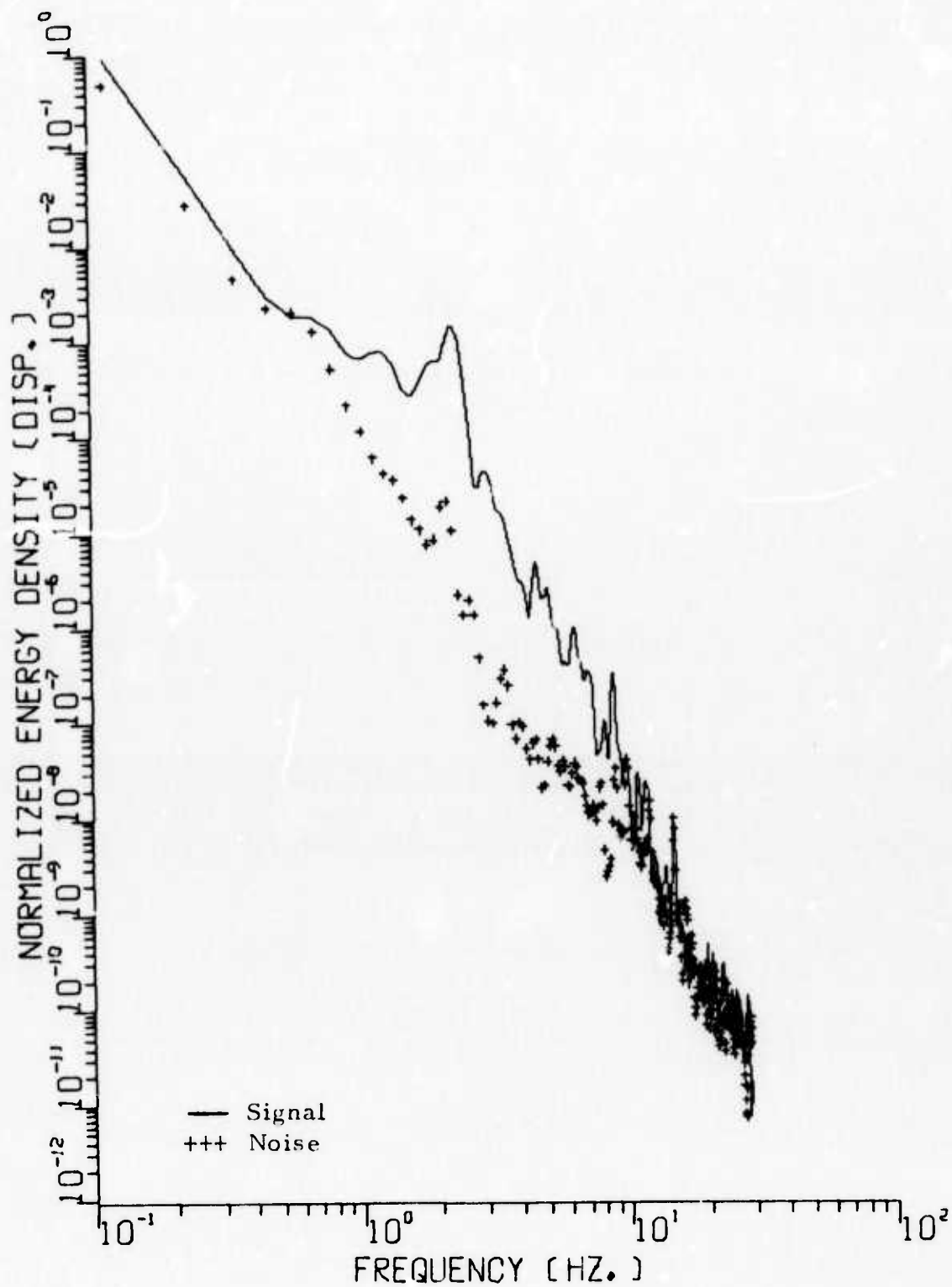


FIGURE I-1c

THE NORMALIZED ENERGY DENSITY DISPLACEMENT SPECTRUM OF  
THE SIGNAL AND NOISE FOR THE BEAR VALLEY EARTHQUAKE  
OF JUNE 22, 1973 RECORDED AT SITE 8 (N45E COMPONENT)



TABLE I-1  
PARAMETERS FROM SPECTRAL ANALYSIS OF  
NEAR FIELD ACCELEROGRAM DATA  
(PAGE 1 OF 5)

Event/Site	M <sub>L</sub> Local Magnitude	R Hypocentral Distance (km)	Corner Frequency f <sub>o</sub> (Hz)	Low Frequency Spectral Level Ω <sub>o</sub> (cm-sec)	Seismic Moment M <sub>o</sub> (dyne-cm)
Bear Valley (6-22-73)	3.5	10.6	2.7	0.034	3.92 x 10 <sup>22</sup>
Station 2					
Station 4					
Station 7					
Station 8					
San Fernando Earthquake Series (2-9-71)	6.6	11.1	2.2	0.097	1.20 x 10 <sup>23</sup>
Main Shock					
Pacoima Dam					
Orion Boulevard					
First Street					
Figueroa Street					
	6.6	16.4	0.60	22.8	4.12 x 10 <sup>25</sup>
	6.6	28.5	0.60	12.1	3.81 x 10 <sup>25</sup>
	6.6	46.1	0.73	2.9	1.50 x 10 <sup>25</sup>
	6.6	46.1	0.93	2.5	1.30 x 10 <sup>25</sup>

TABLE 1-1  
PARAMETERS FROM SPECTRAL ANALYSIS OF  
NEAR FIELD ACCELEROGRAM DATA  
(PAGE 2 OF 5)

Event/Site	M <sub>L</sub> Local Magnitude	R Hypocentral Distance (km)	Corner Frequency f <sub>o</sub> (Hz)	Low Frequency Spectral Level Ω <sub>o</sub> (cm-sec)	Seismic Moment M <sub>o</sub> (dyne-cm)
Aftershocks Recorded At Pacoima Dam	5.5	18.0	5.0	0.029	5.76 x 10 <sup>22</sup>
	4.9	15.0	4.3	0.012	1.90 x 10 <sup>22</sup>
	4.8	12.0	5.5	0.013	1.75 x 10 <sup>22</sup>
	5.4	12.0	3.0	0.090	1.18 x 10 <sup>23</sup>
	4.4	7.0	6.7	0.006	4.70 x 10 <sup>21</sup>
	4.6	17.0	3.7	0.010	1.86 x 10 <sup>22</sup>
Kern County (6-21-52)	7.7				
Pasadena		126.9	0.94	1.47	2.05 x 10 <sup>25</sup>
Taft		41.4	1.3	1.33	8.32 x 10 <sup>24</sup>
Hollywood Stage B		120.3	0.90	1.10	1.46 x 10 <sup>25</sup>

TABLE I-1  
PARAMETERS FROM SPECTRAL ANALYSIS OF  
NEAR FIELD ACCELEROGRAM DATA  
(PAGE 3 OF 5)

Event/Site	M <sub>L</sub> Local Magnitude	R Hypocentral Distance (km)	Corner Frequency f <sub>o</sub> (Hz)	Low Frequency Spectral Level Ω <sub>o</sub> (cm-sec)	Seismic Moment M <sub>c</sub> (dyne-cm)
Borrego Mountain (4-8-68)	6.5				
El Centro		67.3	0.50	7.12	5.26 x 10 <sup>25</sup>
San Diego		107.3	0.72	1.38	1.62 x 10 <sup>25</sup>
San Onofre		134.3	0.72	1.10	1.62 x 10 <sup>25</sup>
Parkfield (6-27-66)	5.6				
Station 2		58.6	1.4	2.39	1.54 x 10 <sup>25</sup>
Station 5		56.1	2.0	0.81	4.97 x 10 <sup>24</sup>
Station 8		83.7	2.3	0.37	3.38 x 10 <sup>24</sup>
Station 12		53.5	2.2	0.088	5.18 x 10 <sup>23</sup>
Temblor		59.6	2.6	0.53	3.47 x 10 <sup>24</sup>
Western Washington (4-13-49)	7.1				
Seattle		57.7	1.2	2.22	1.4 x 10 <sup>25</sup>
Olympia		16.9	1.1	4.54	8.4 x 10 <sup>24</sup>

TABLE I-1  
PARAMETERS FROM SPECTRAL ANALYSIS OF  
NEAR FIELD ACCELEROGRAM DATA  
(PAGE 4 CF 5)

Event/Site	M <sub>L</sub> Local Magnitude	R Hypocentral Distance (km)	Corner Frequency f (Hz) f <sub>o</sub>	Low Frequency Spectral Level Ω <sub>o</sub> (cm-sec)	Seismic Moment M <sub>o</sub> (dyne-cm)
Puget Sound (4-29-49) Olympia	6.5	60.9	1.1	1.69	1.13 x 10 <sup>25</sup>
Helena, Montana (10-31-35) Helena	6.0	5.82	2.4	0.21	1.32 x 10 <sup>23</sup>
North West, California (9-11-38) Ferndale	5.5	55.1	2.4	0.23	1.37 x 10 <sup>24</sup>
North West, California (2-9-41) Ferndale	6.6	103.6	1.6	0.25	2.84 x 10 <sup>24</sup>

TABLE I-1  
PARAMETERS FROM SPECTRAL ANALYSIS OF  
NEAR FIELD ACCELEROGRAM DATA  
(PAGE 5 OF 5)

Event/Site	M <sub>L</sub> Local Magnitude	R Hypocentral Distance (km)	Corner Frequency f <sub>o</sub> (Hz)	Low Frequency Spectral Level f <sub>o</sub> (cm-sec)	Seismic Moment M <sub>o</sub> (dyne-cm)
Northern, California (9-22-52) Ferndale	5.5	43.2	1.3	0.72	3.38 x 10 <sup>24</sup>
Wheeler Ridge (1-12-54) Taft	5.9	42.8	1.4	0.36	1.68 x 10 <sup>24</sup>

Pacoima Dam. The Bear Valley event of June 22, 1973, was obtained from the University of California accelerometer array at Bear Valley, California. This low magnitude event ( $M_L = 4.0$ ) was recorded by four stations relatively near the source ( $\sim 10$  km). From the previously described spectra, (and using only stations 7 and 8 because of their clear waveforms), we obtained a corner frequency ( $f_o$ ) of approximately 2.2 Hz and a low frequency spectral level ( $\Omega_o$ ) of about 0.12 cm-sec. Using the theory of Brune (1970) on these data leads to a seismic moment ( $M_o$ ) of about  $1.4 \times 10^{23}$  dyne-cm and a stress drop ( $\Delta\sigma$ ) of about 300 bars.

The significance of this latter number is not clear. Discussions conducted at the last Near Field Study group meeting (November 19 and 20, 1974 at Cal Tech) produced varied opinions which judged this stress drop to be either acceptable or too high a value. Using the Brune theory on the other seventeen events produced even more controversial results, with several events yielding stress drops in the kilobar range (i.e., Kern County - 4.4 kbar). A decision on how this number from Brune's theory can be compared to the breaking strength of materials in the laboratory has not been reached.

Finally, an attempt was made to determine a correlation between local magnitude ( $M_L$ ) and corner frequency ( $f_o$ ) using the events listed in Table I-1. For events with a local magnitude greater than 5.5, the corner frequency tends to decrease in a linear fashion with increasing local magnitude (see Figure I-2). Events with magnitudes less than 5.5 follow no particular pattern but, of course, our data sample is limited. These latter events are characterized by small fault area ( $\sim 1 \text{ km}^2$ ) and relatively high stress drop ( $\Delta\sigma > 200$  bars). Obviously, the analysis of more events with local magnitudes ( $M_L$ ) less than 5.5 is needed for the identification of any trends in this magnitude range.





#### D. CONCLUSIONS

The analysis of near-field accelerogram spectra has produced little in the way of significant results, either because of the lack of data, or the inadequacy of the theory to explain the observations. The next several months will be spent analyzing several events in conjunction with other investigators of the Near Field Study Group. Both Cal Tech and University of California acceleration data will be used with long-period data from several sets of instrumentation. From both spectral analysis and waveform matching procedures using the Cagnaird and Haskell dislocation sources, it is hoped conclusions can be reached on the relationship of corner frequency to local magnitude and its association with stress drop.

## SECTION II

### FAR FIELD SOURCE STUDIES

#### A. INTRODUCTION

For the past several months, the examination of far-field spectra for source characteristics has been conducted along several lines of investigation. The implementation of the de-multipathing procedures previously described by Turnbull, et al., (1974), on the PDP-15 interactive graphics system, is described in Subsection B. Software has also been written for three-dimensional computer plots of double-couple source spectra, and examples of these displays is given in Subsection C. This plot is quite effective in showing the spectral variation as a function of the source parameters (depth, strike, dip, slip), their relative importance to the spectral variation, and the existence of spectral holes or other identifying characteristics of particular source configurations. In Subsection D, we present a result from the study of radiation pattern invariance as a function of source parameters; in particular, theoretical LQ/LR ratios for earthquakes are given for averaged azimuthal increments. Also, an attempt to reduce the scatter in  $M_s - m_b$  plots using the relative invariance to the total energy in the surface-wave train is discussed. Finally in Subsection E, we summarize our results and discuss future plans.

#### B. IMPLEMENTATION OF INTERACTIVE GRAPHICS FOR DE-MULTIPATHING OF SURFACE-WAVE SPECTRA

A procedure for de-multipathing surface-wave spectra, as shown in Figures II-1 through II-4, has been implemented on the PDP-15 interactive graphics system by Ringdal and Shaub (1974). As described by

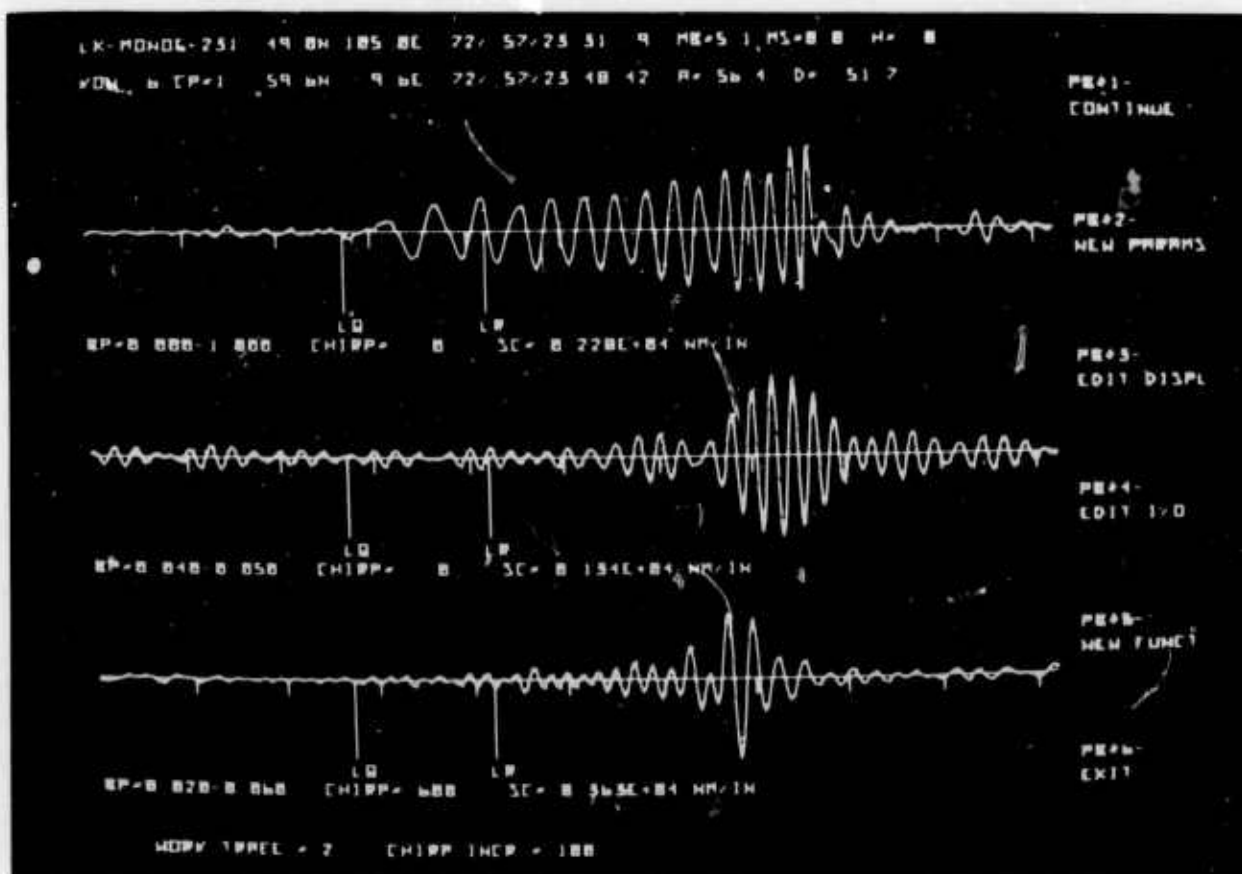


FIGURE II-1

EXAMPLE OF AN ORIGINAL EVENT WAVEFORM  
(TOP TRACE), FILTERED BY A NARROWBAND FILTER  
(MIDDLE TRACE) AND BY A LINEAR CHIRP  
FILTER (BOTTOM TRACE)

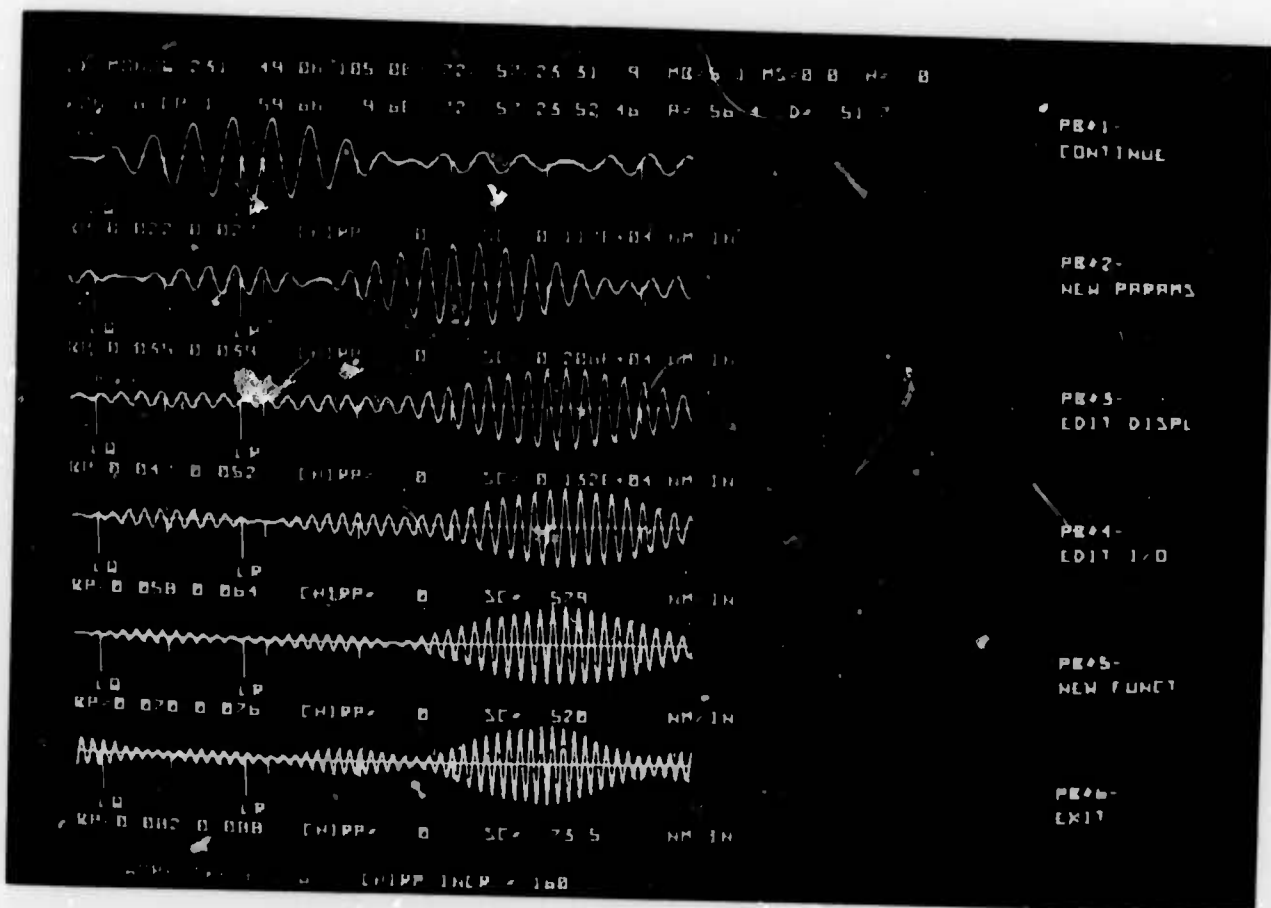


FIGURE II-2  
 DISPLAY OF A SET OF NARROWBAND FILTER  
 OUTPUT TRACES FOR A DISPERSED WAVEFORM

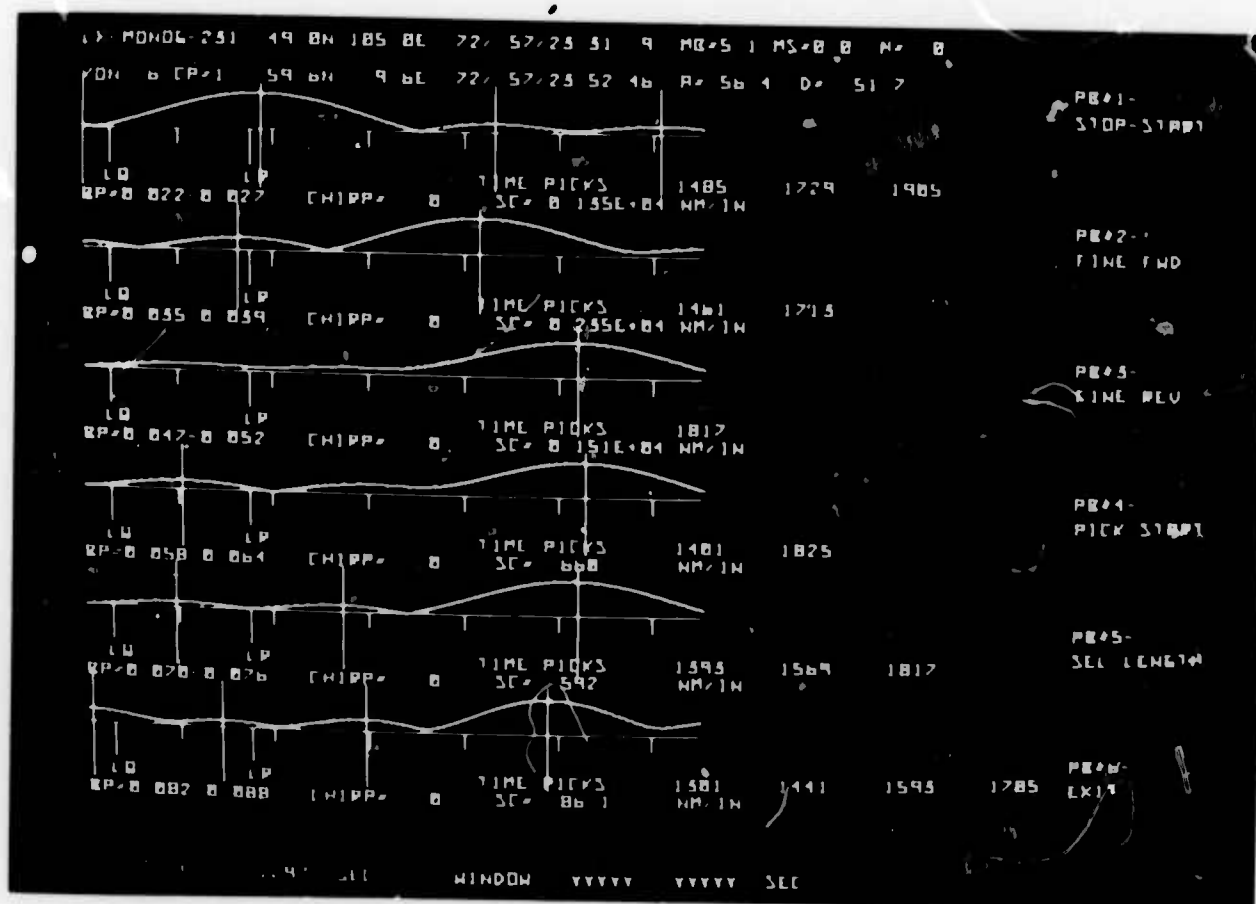


FIGURE II-3  
A SET OF ENVELOPES (HILBERT TRANSFORMS)  
OF A SUITE OF NARROWBAND FILTERED TRACES  
THE CURSOR MARKS INDICATE ANALYST TIME PICKS

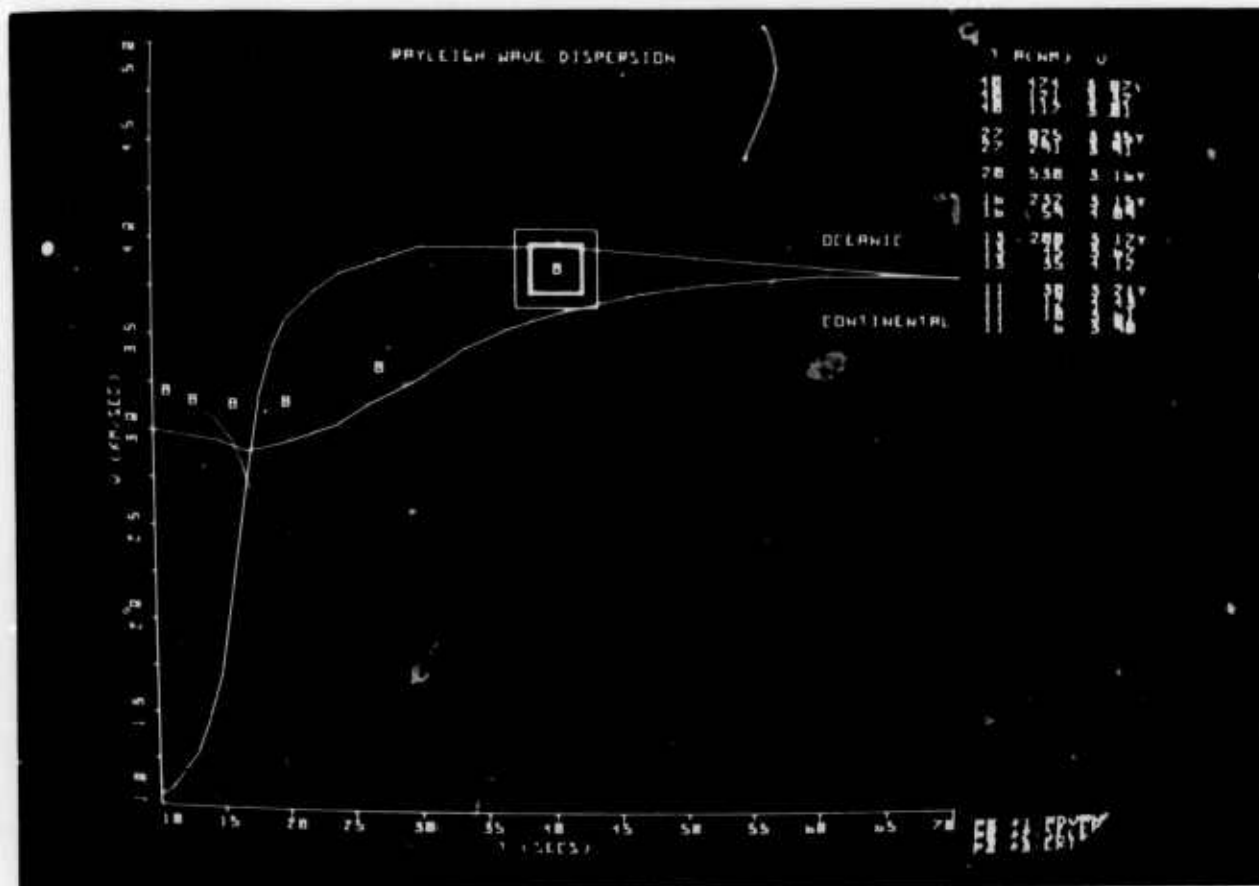


FIGURE II-4  
CONSTRUCTION OF A GROUP VELOCITY  
CURVE VIA THE INTERACTIVE DISPLAY

Turnbull, et al., (1974), a reasonable measure of success has been achieved using a suite of narrowband filters over the 10 to 60 second period range to eliminate multipath effects from the surface-wave spectra. This procedure, though, using normal computer analysis, is quite time consuming. With future research including large suites of events from particular areas of interest, the need for an automated approach was quite evident. These figures show photographs of the displays of the major steps in this procedure, which are summarized as follows:

- Figure II-1 displays the original wavetrain (either Rayleigh or Love), the event parameters (location, etc.), the result of a narrowband filter, and the application of a linear chirp filter (used for detection purposes). This display is used to pick the group velocity window of the surface-wave component under consideration.
- Figure II-2 shows a set of narrowband filter output traces for the chosen group velocity window. We see that, for the frequencies examined, little multipathing exists, as shown by the dominant group velocity wave packets. Multipathing severely affects the spectra when, for the same frequency, two or more group velocity wave packets exist with comparable amplitudes.
- In Figure II-3, a set of envelope functions (calculated using Hilbert Transforms) are displayed for the set of narrowband filter traces shown in Figure II-2. These envelopes facilitate the picking of the maximum amplitudes of the wave packets at each frequency, and are indicated by the cursor marks.
- Finally, in Figure II-4, the maximum amplitude picks are displayed with standard oceanic and continental group velocity curves. The table in the upper right hand corner of the display gives the period, amplitude, and group velocity of each



of the picks. When a choice of a pick is made at a particular frequency, the choice is boxed and noted in the table.

This procedure will be completed when the software is written to produce a hard copy of the spectra resulting from the chosen group velocity curve. Using this procedure, areas of interest can be studied using spectral fitting techniques on de-multipathed spectra.

### C. VARIATION OF DOUBLE COUPLE SOURCE SPECTRA AS A FUNCTION OF SOURCE PARAMETERS

Using a normal Gutenberg-Bullen earth structure, Rayleigh and Love wave spectra for a double couple source have been formulated in three-dimensional displays. The displays are helpful in examining source spectral variation as a function of the source parameters (depth, strike, dip, slip), and the existence of spectral holes or other identifying characteristics of a particular source configuration. Four examples of these displays are shown in Figures II-5 to II-8. We can summarize their major features as follows:

- The variation of double couple Rayleigh and Love wave spectra with depth and dip for a strike-slip fault is shown in Figures II-5a, II-5b. Both the Rayleigh and Love wave spectra are fairly smooth except for a vertical fault ( $\delta(\text{dip}) = 90^\circ$ ), where a hole appears in the Rayleigh spectra.
- The variation of double couple Rayleigh and Love wave spectra with depth and strike for a vertical strike-slip fault is shown in Figures II-6a, II-6b. The major features in these spectra are the hole in the Rayleigh wave spectra as in the previous case, and the consistency of the nodes in the spectra as a function of depth. For this particular configuration, we see that

# GUTENBERG-B/RAYLEIGH

DOUBLE-COUPLE

SLIP ANGLE= 0.0

STRIKE= 0.0

MOMENT= 0.10

AZIMUTH= 30.0

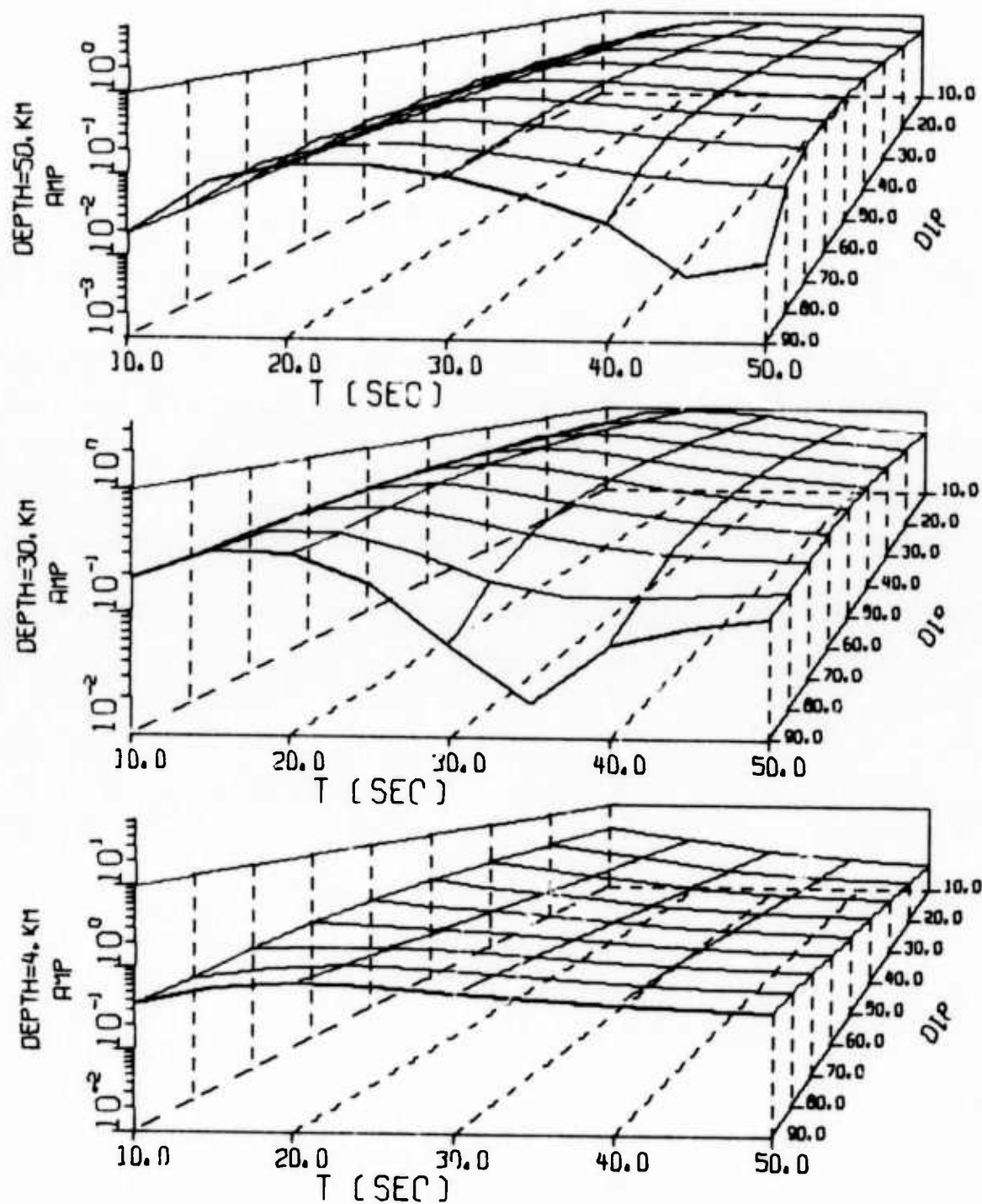


FIGURE II-5a

VARIATION OF DOUBLE COUPLE RAYLEIGH WAVE SPECTRA  
WITH DEPTH AND DIP FOR A STRIKE-SLIP FAULT

# GUTENBERG-B / LOVE

DOUBLE-COUPLE

SLIP ANGLE= 0.0

STRIKE= 0.0

MOMENT= 0.10

AZIMUTH= 30.0

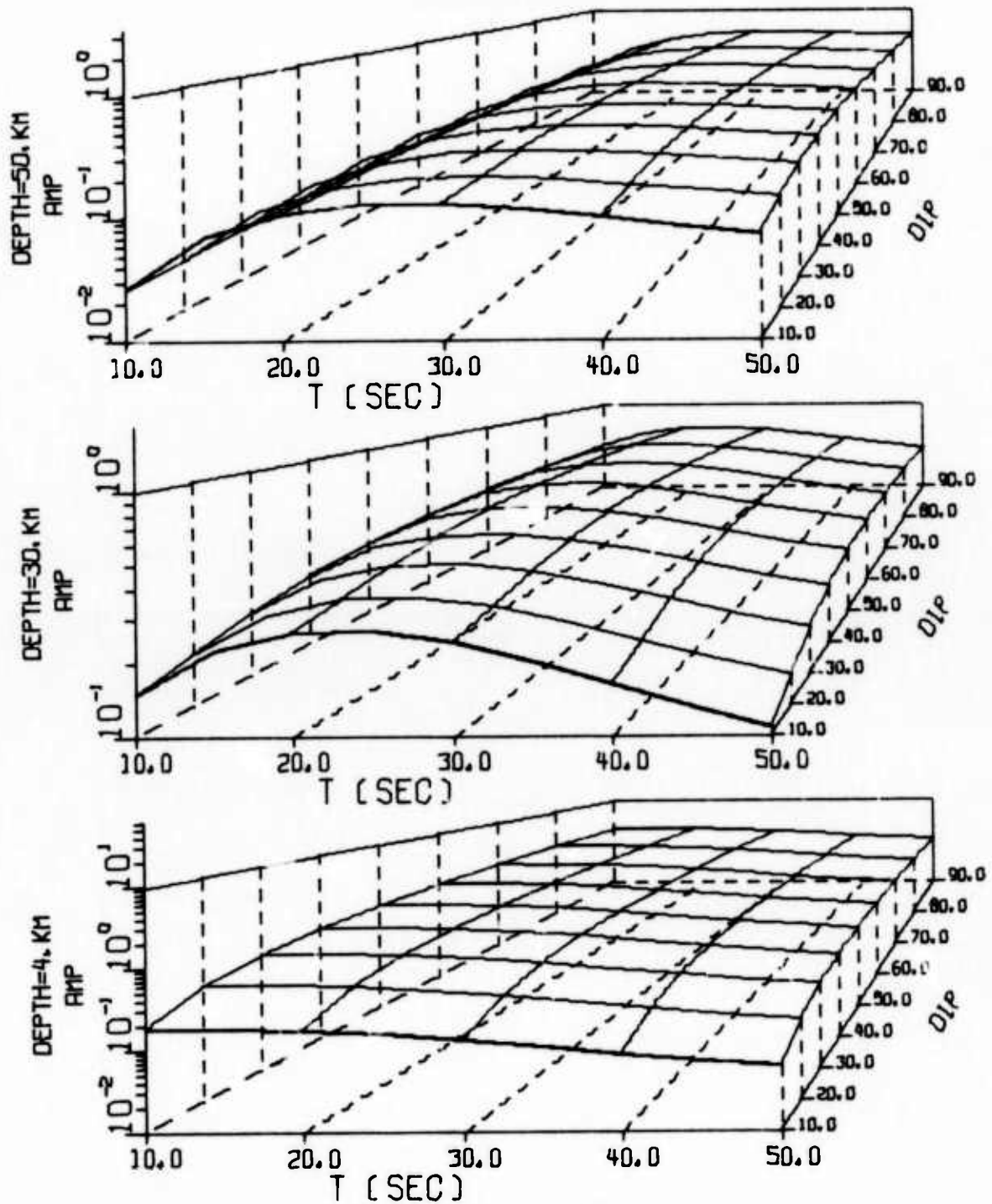


FIGURE II-5b

VARIATION OF DOUBLE COUPLE LOVE WAVE SPECTRA WITH  
DEPTH AND DIP FOR A STRIKE-SLIP FAULT

# GUTENBERG-B/RAYLEIGH

DOUBLE-COUPLE

DIP ANGLE= 90.0

SLIP ANGLE= 0.0

MOMENT= 0.10

AZIMUTH= 30.0

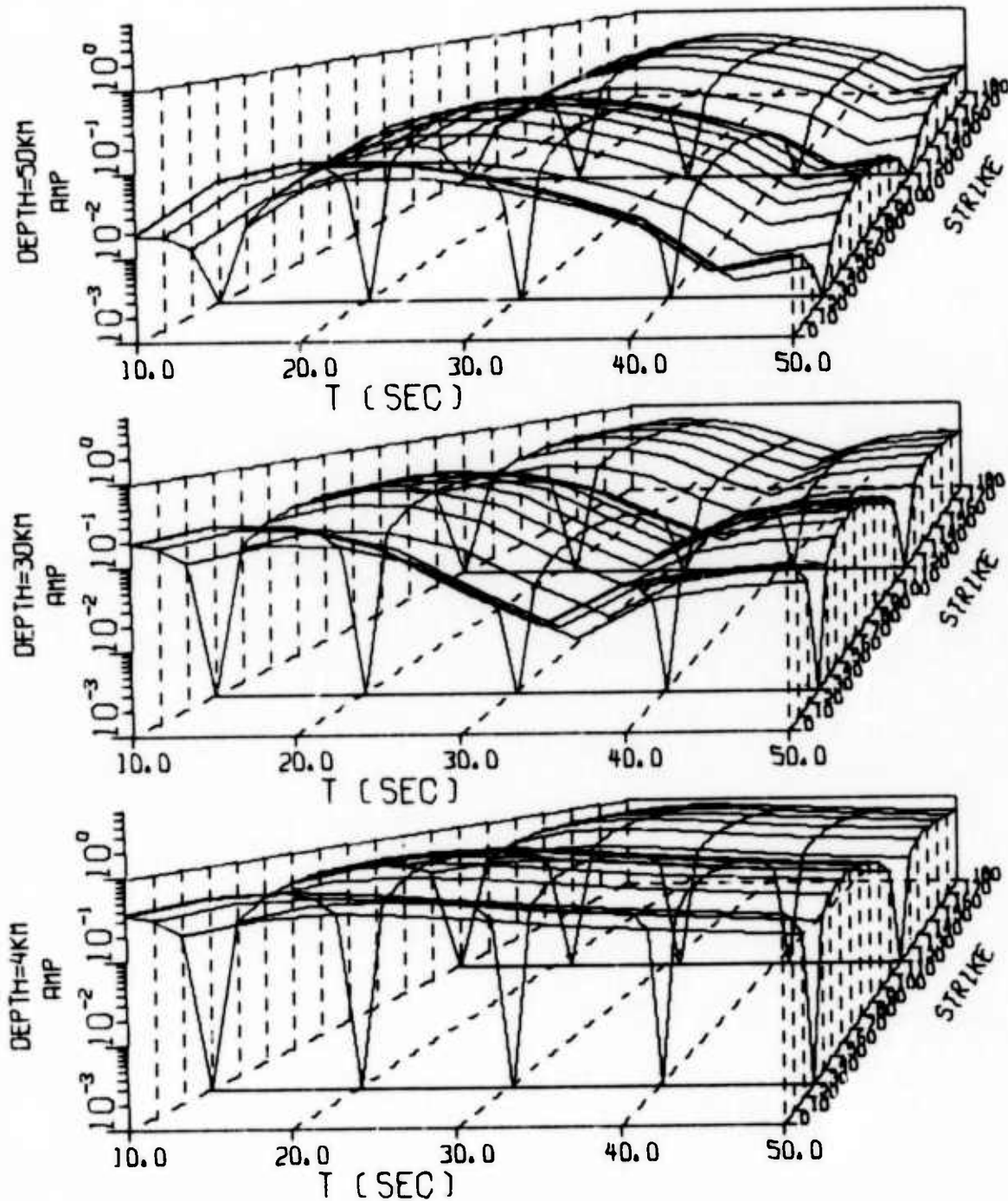


FIGURE II-6a

VARIATION OF DOUBLE COUPLE RAYLEIGH WAVE SPECTRA WITH  
DEPTH AND STRIKE FOR A VERTICAL STRIKE-SLIP FAULT

# GUTENBERG-B / LOVE

DOUBLE-COUPLE

DIP ANGLE= 90.0

SLIP ANGLE= 0.0

MOMENT= 0.10

AZIMUTH= 30.0

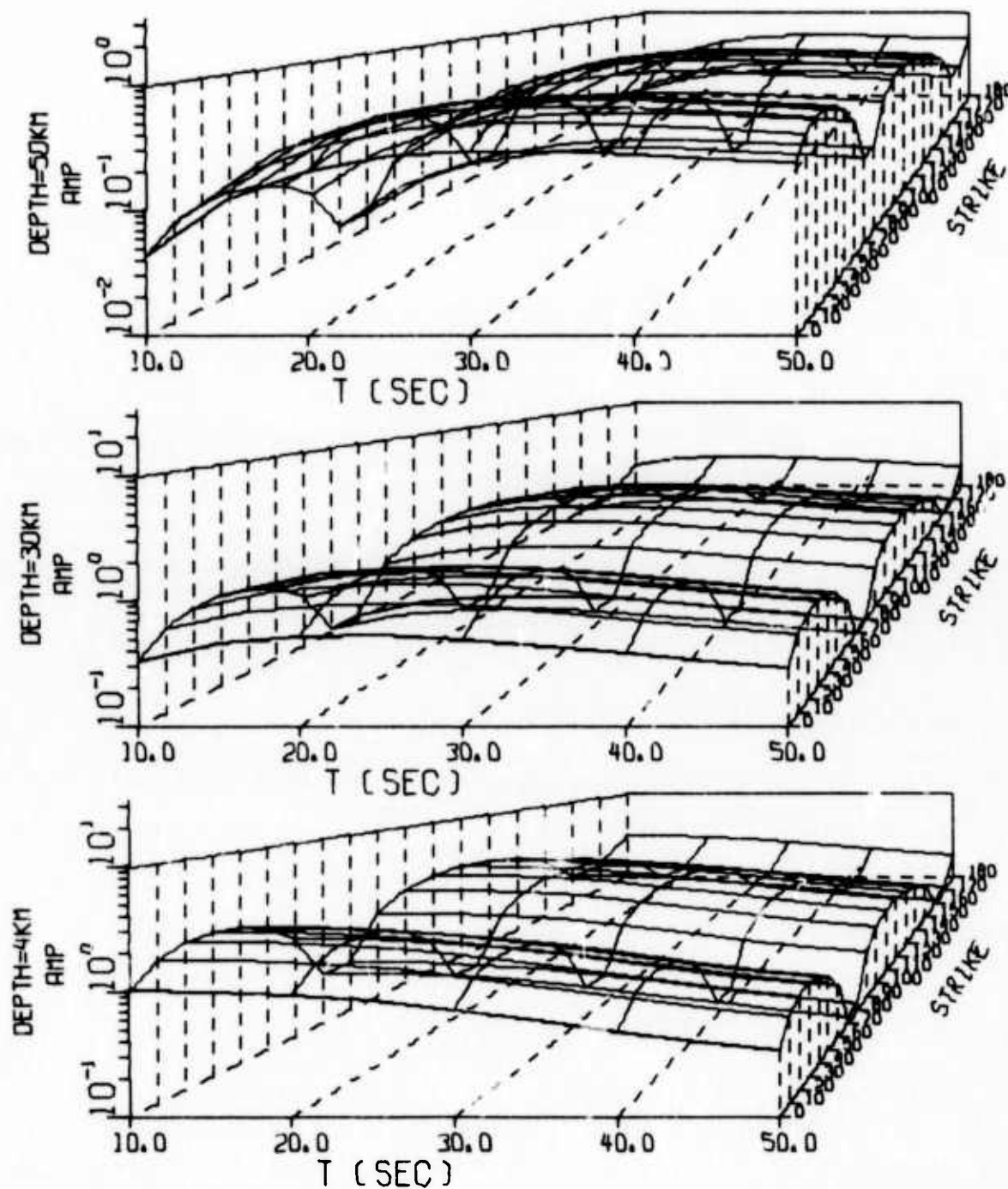


FIGURE II-6b

VARIATION OF DOUBLE COUPLE LOVE WAVE SPECTRA WITH DEPTH  
AND STRIKE FOR A VERTICAL STRIKE-SLIP FAULT



these nodes do not change azimuth with a change in depth (this would not be true in general).

- Figures 11-7a, 11-7b show the variation of Rayleigh and Love wave spectra with depth and slip for a vertical fault, while Figures 11-8a, 11-8b show the same variation for a moderately dipping ( $60^{\circ}$ ) fault. For the Rayleigh wave spectra, we see that the hole exists for the same slip angle ( $0^{\circ}$ ) at all depths for a vertical fault, while for the moderately dipping fault the same situation exists, but for a different slip angle ( $-60^{\circ}$ ). The Love wave spectra is quite smooth for both cases, except a lower spectral level exists at all depths for one particular slip angle of the moderately dipping fault.

These plots represent the initial results of a detailed study of spectral variation as a function of source parameters. Combined with previously generated two-dimensional spectral plots, identifying characteristics of source configurations and the variation of spectral level will be exhaustively analyzed.

#### D. A BRIEF EXAMINATION OF TWO FAMILIAR DISCRIMINANTS

From the previously discussed studies of surface-wave radiation patterns and spectra, and the work by Alexander and Turnbull (1974) on the invariance of fundamental mode surface-wave energy (i. e.,  $LR^2 + LQ^2$ ,  $LQ/LR$ ) as a function of source parameters, brief investigations have been conducted on two widely used discriminants of earthquakes and explosions. The first discriminant, the ratio of Love wave to Rayleigh wave spectral amplitude ( $LQ/LR$ ), was examined from the perspective of the possible theoretical variation of this ratio for earthquakes due to variation of the source parameters. In Figure 11-9, the results of this examination are presented for three focal

# GUTENBERG-B/RAYLEIGH

DOUBLE-COUPLE

DIP ANGLE= 90.0

STRIKE= 0.0

MOMENT= 0.10

AZIMUTH= 30.0

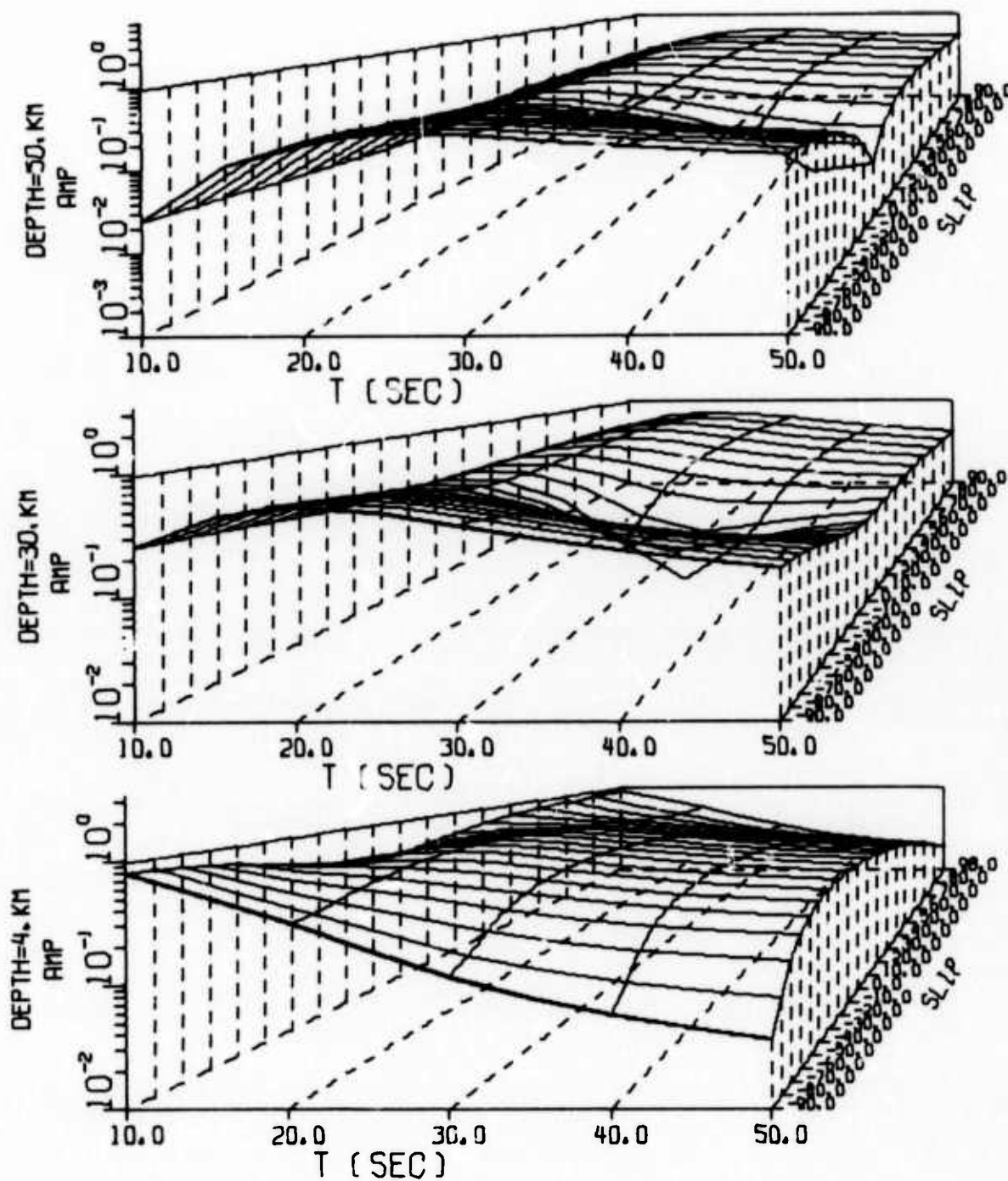


FIGURE II-7a

VARIATION OF DOUBLE COUPLE RAYLEIGH WAVE SPECTRA  
WITH DEPTH AND SLIP FOR A VERTICAL FAULT



# CUTENBERG-B / LOVE

DOUBLE-COUPLE

DIP ANGLE= 90.0

STRIKE= 0.0

MOMENT= 0.10

AZIMUTH= 30.0

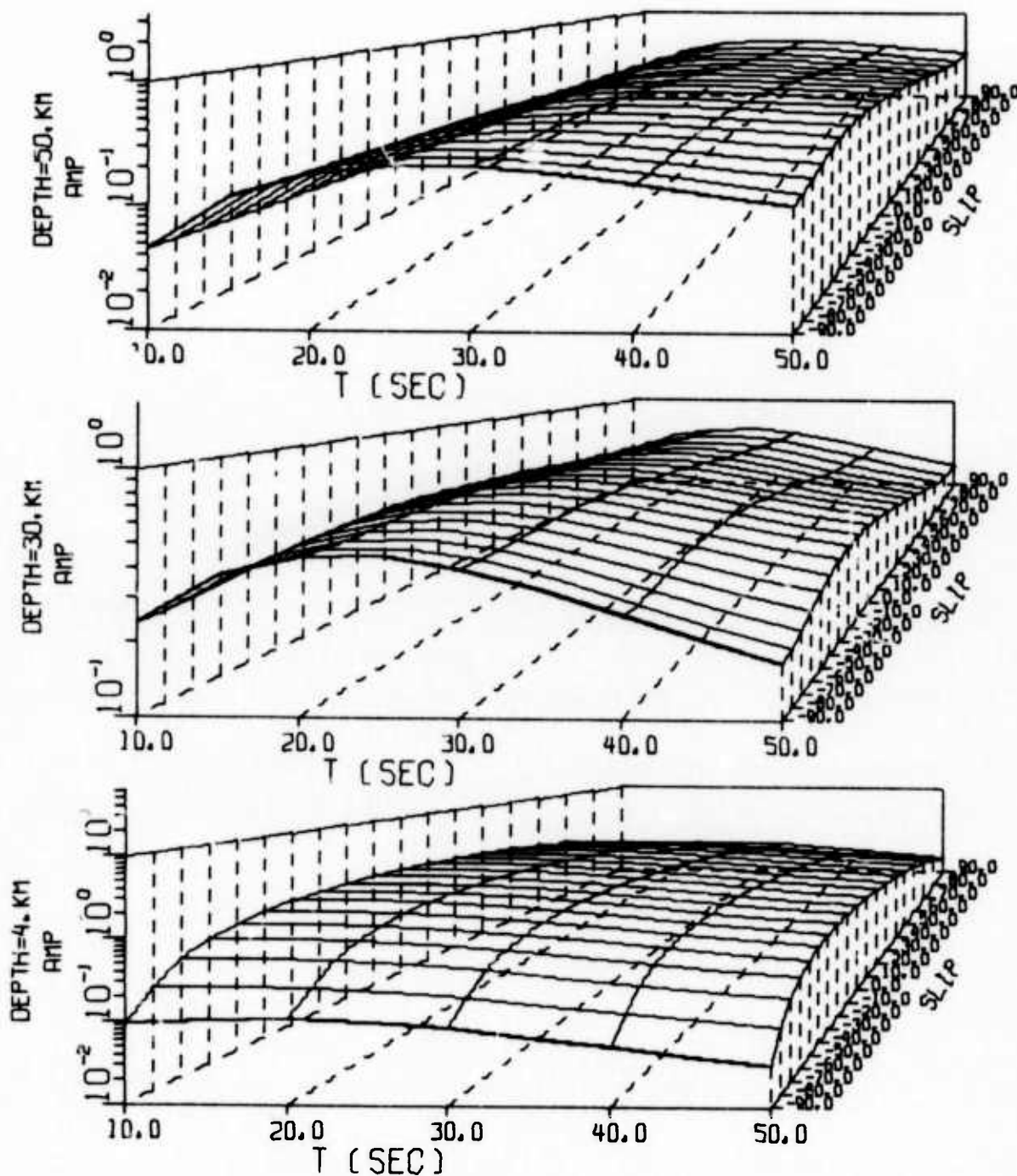


FIGURE II-7b

VARIATION OF DOUBLE COUPLE LOVE WAVE SPECTRA WITH  
DEPTH AND SLIP FOR A VERTICAL FAULT

# GUTENBERG-B/RAYLEIGH

DOUBLE-COUPLE

DIP ANGLE= 60.0

STRIKE= 0.0

MOMENT= 0.10

AZIMUTH= 30.0

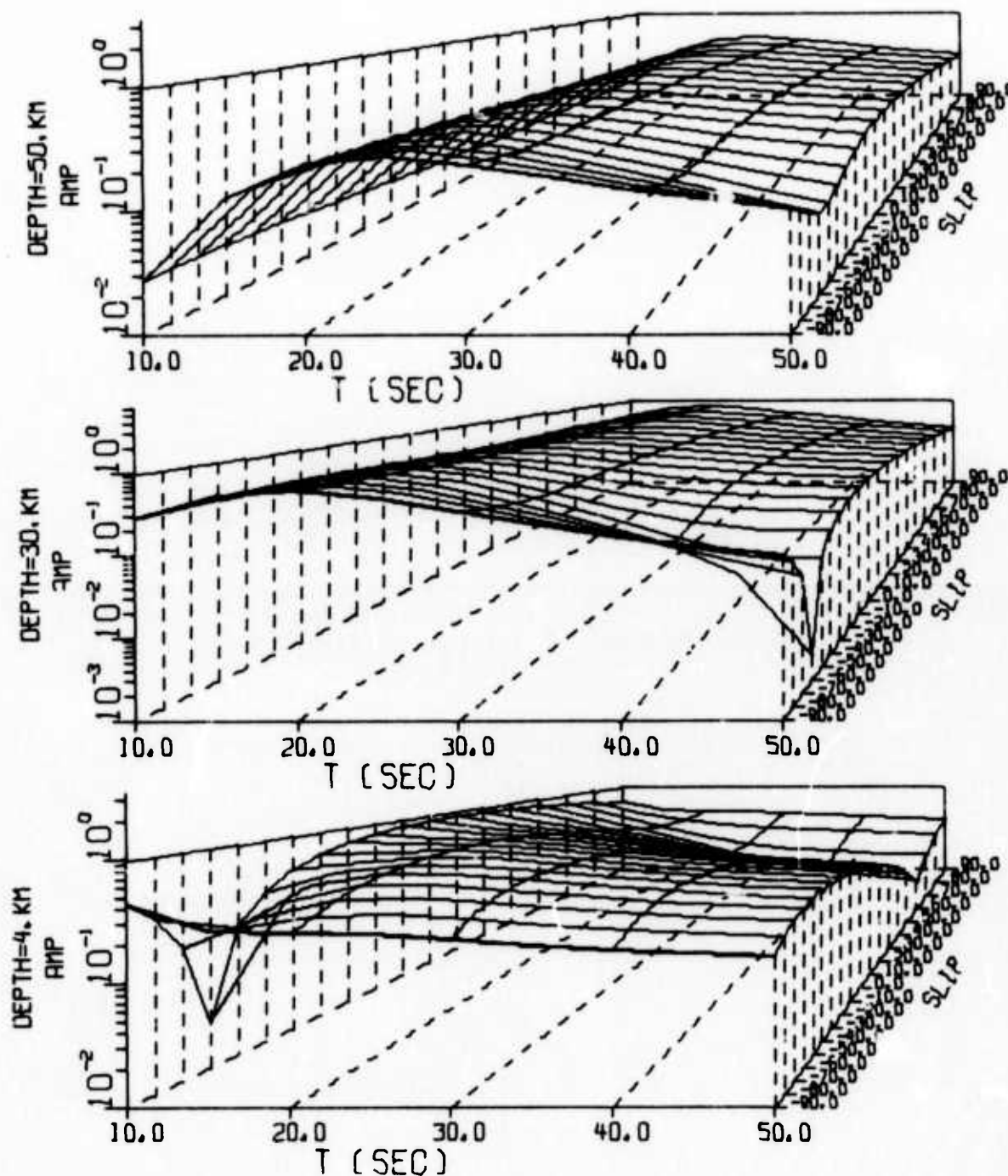


FIGURE II-8a

VARIATION OF DOUBLE COUPLE RAYLEIGH WAVE SPECTRA WITH DEPTH AND SLIP FOR A MODERATELY DIPPING (60°) FAULT

# GUTENBERG-B / LOVE

DOUBLE-COUPLE

DIP ANGLE= 60.0

STRIKE= 0.0

MOMENT= 0.10

AZIMUTH= 30.0

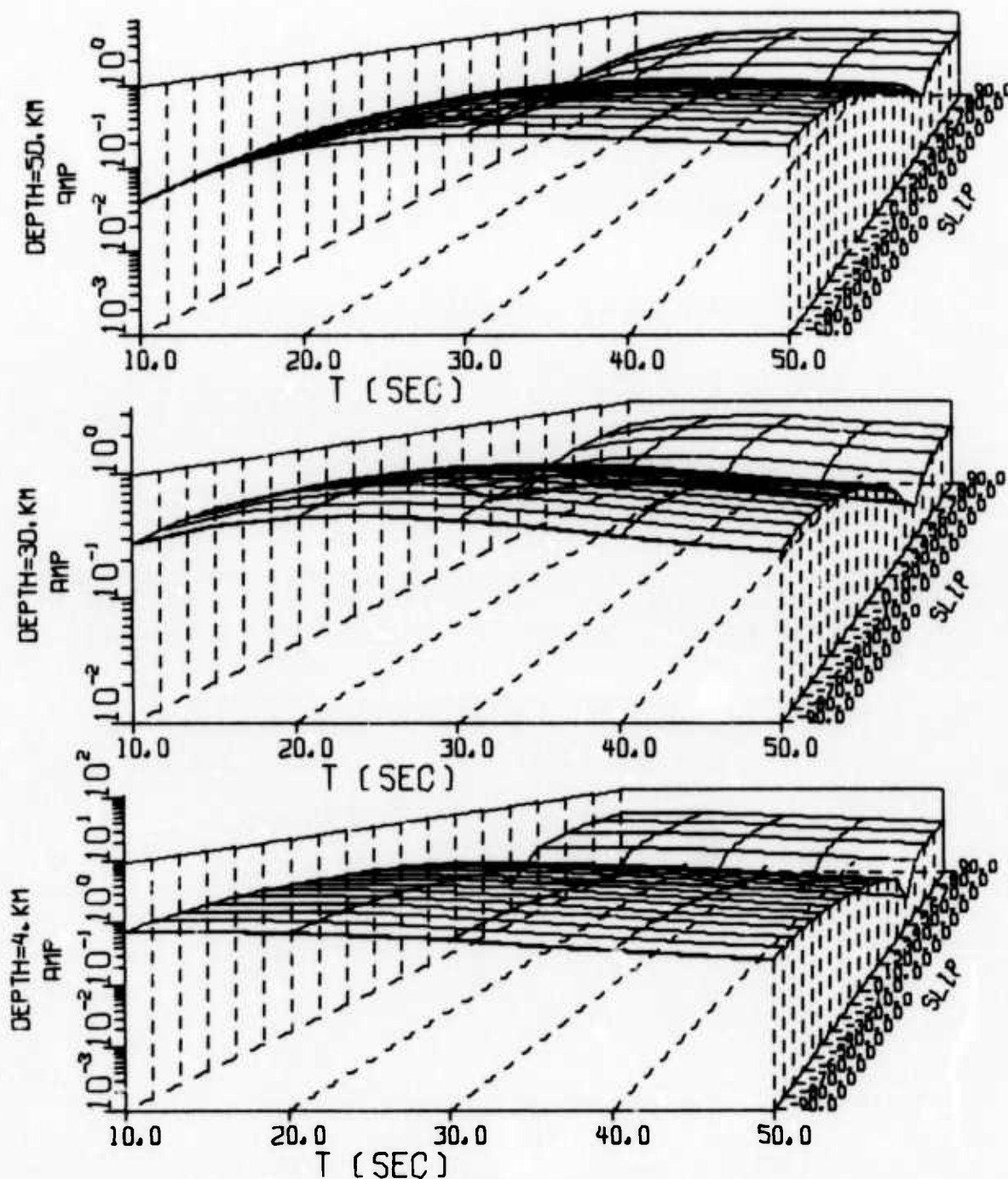


FIGURE II-8b

VARIATION OF DOUBLE COUPLE LOVE WAVE SPECTRA WITH DEPTH AND SLIP FOR A MODERATELY DIPPING (60°) FAULT

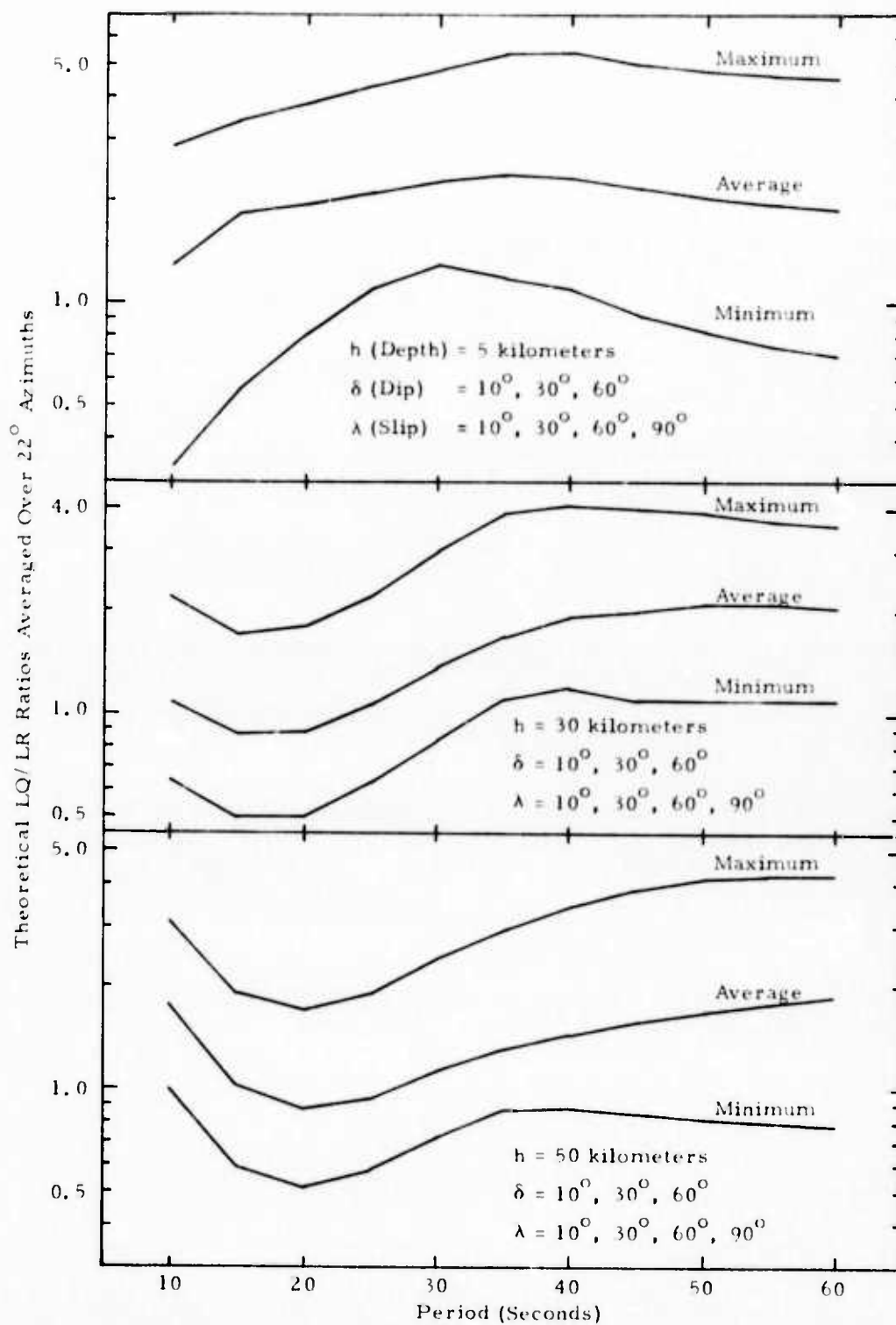


FIGURE II-9  
THEORETICAL LQ/LR RATIOS FOR EARTHQUAKES  
AT THREE FOCAL DEPTHS

depths ( $h = 5, 30, 50$  kilometers). The theoretical LQ/LR ratios are averaged over  $22^\circ$  azimuthal increments. This increment was determined by averaging over successively larger azimuthal intervals and determining if the average stayed within 10% of the largest and smallest values. Hence radiation pattern effects are minimized. We see from the figure that the average LQ/LR value at 30 seconds period is very close to or greater than 1 for the three focal depths. This agrees with the results of Lambert, et al., (1974), in his study of data recorded by VLPE instruments.

The second discriminant,  $M_s - m_b$ , was studied with the objective of reducing the scatter of the earthquake population by minimizing the effect of the source mechanism radiation pattern and by obtaining the  $M_s$  value at the same period for all events and all components. The three following cases illustrate our results.

- Figures II-10a, II-10b illustrate the case of  $M_s$  measurements obtained from one station by manual measurement directly from the record. These events originated in Eurasia, were recorded on all three components at NORSAR in 1972, and consist of 137 earthquakes and 6 presumed explosions. In Figure II-10a, the standard deviation about the mean line for earthquakes was found to be  $\sigma = 0.279$  for  $M_s$  calculated in the standard manner using the vertical Rayleigh wave trace. Next, using our knowledge of Rayleigh and Love wave radiation patterns, we then hoped to reduce the scatter in the earthquake population by calculating a  $M_s$  using both Rayleigh and Love wave measurements (the modulus of the Rayleigh and Love wave amplitudes) from the same data set. By doing this, we are essentially reducing the radiation pattern affect on the measurement (minimizing the affect of nodes and lobal peaks of the patterns). Figure II-10b gives the result of this analysis. No

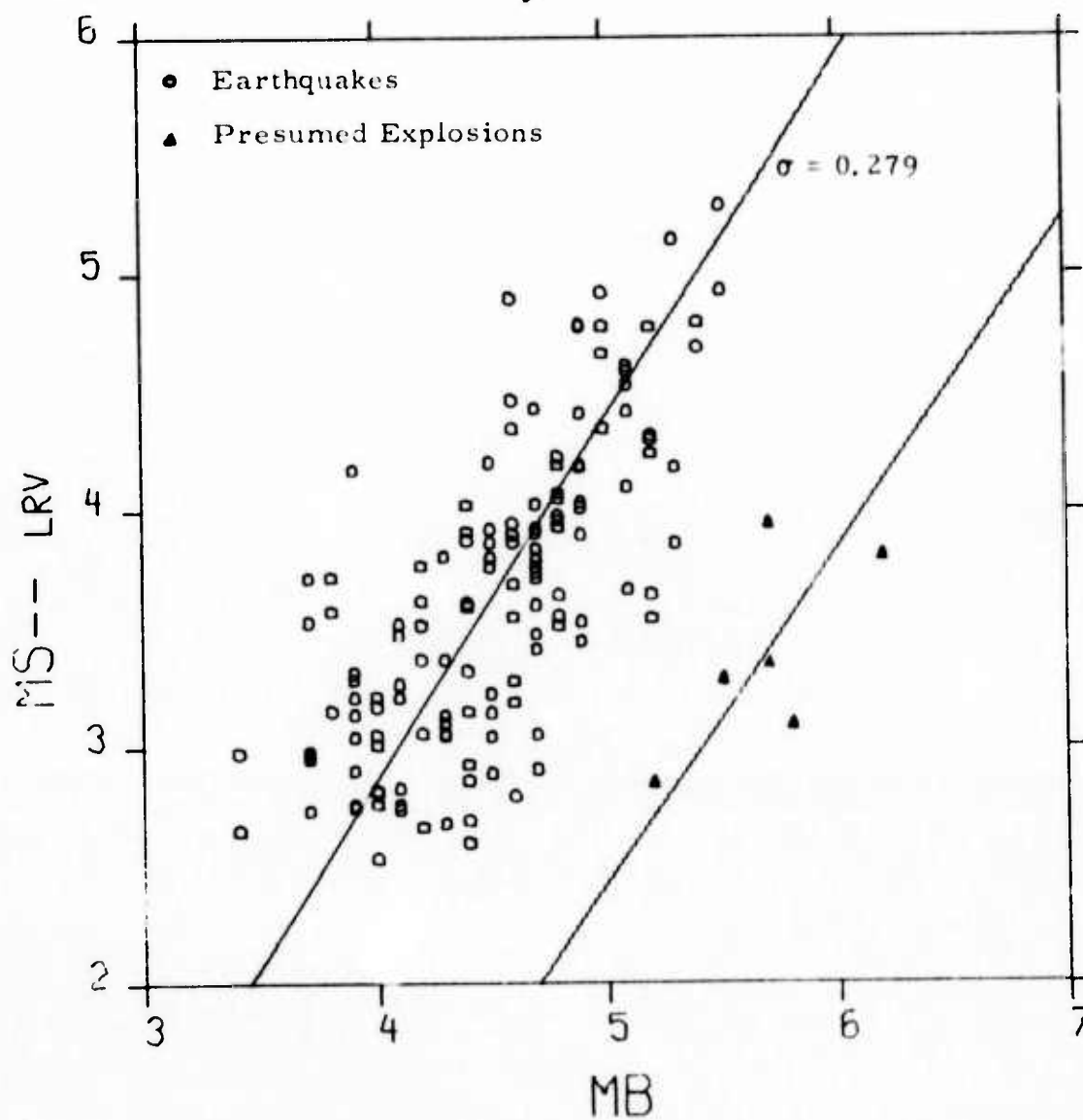


FIGURE II-10a

$M_s - m_b$  FOR EURASIAN EVENTS RECORDED AT NORSAR  
 (1972) -  $M_s$  CALCULATED USING VERTICAL  
 RAYLEIGH COMPONENT ONLY



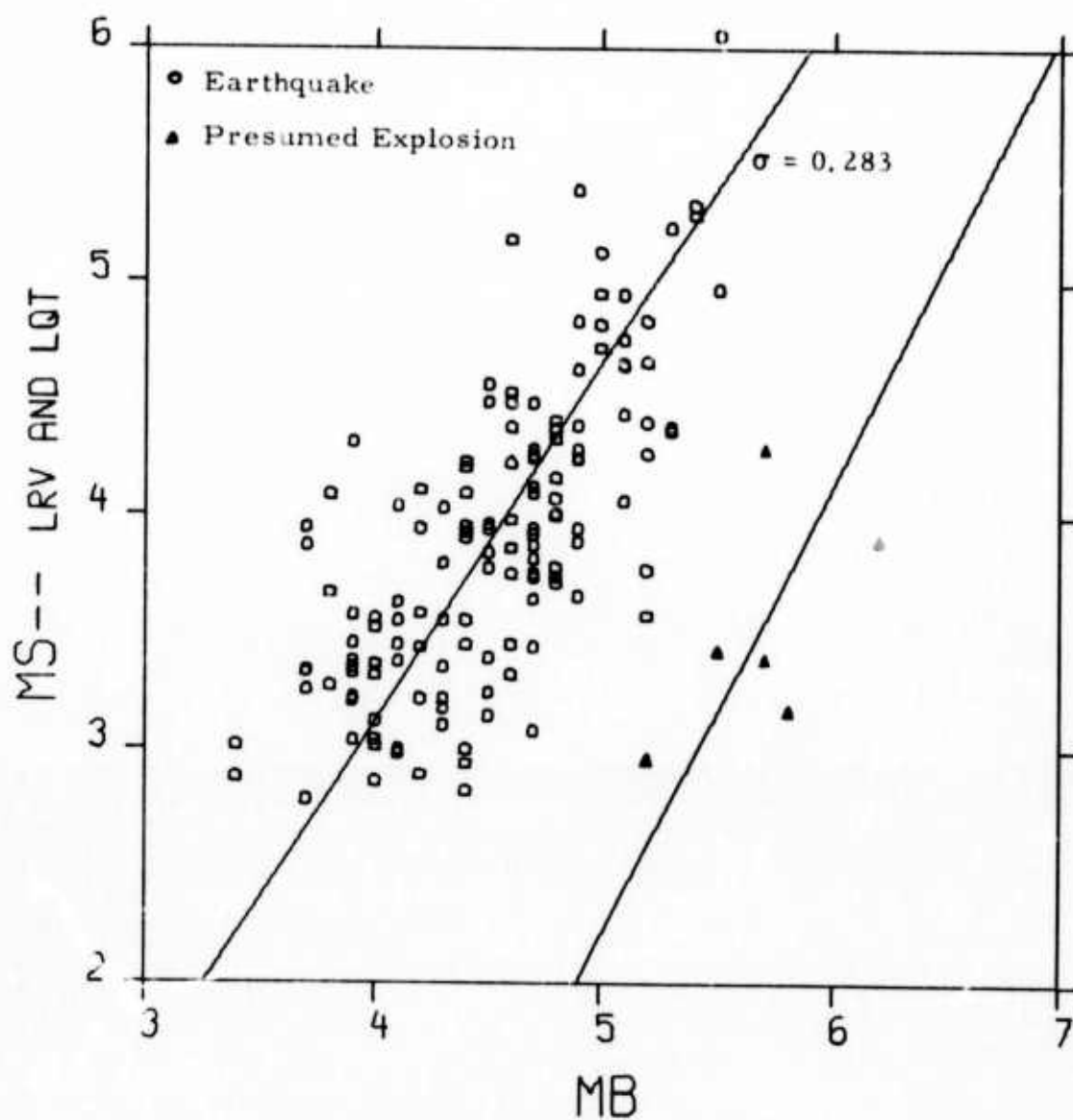


FIGURE II-10b

$M_s - m_b$  FOR EURASIAN EVENTS RECORDED AT NORSAR  
 $(1972) - M_s$  CALCULATED USING BOTH RAYLEIGH  
 AND LOVE WAVE COMPONENTS

improvement in the reduction of scatter was observed, with a standard deviation of  $\sigma = 0.283$ .

- Figures II-11a, II-11b illustrate the case of  $M_s$  measurements averaged at three or more stations (VLPE) by manual measurement of 66 Eurasian earthquakes recorded during 1972 and 1973. By using more stations, it was hoped to reduce radiation pattern effects. In Figure II-11a, a standard deviation of  $\sigma = 0.354$  was obtained using an  $M_s$  calculated from the vertical component Rayleigh wave averaged at three or more stations. This is almost identical to that obtained by Lambert, et al. (1974) for  $M_s$  from single stations. Using an  $M_s$  calculated from both the Rayleigh and Love waves, we obtained a standard deviation of  $\sigma = 0.368$ , essentially no improvement.
- In the final case, using the same VLPE data set and calculating  $M_s$  in the same ways, we obtained our  $M_s$  measurement by using a spectral estimate at 20 seconds period. Figure II-12a illustrates  $M_s$  taken from vertical Rayleigh only, with a standard deviation of  $\sigma = 0.369$ . Using an  $M_s$  obtained from Rayleigh and Love waves (Figure II-12b) yielded a standard deviation of  $\sigma = 0.363$ . Again, no significant improvement.

From these three cases, keeping in mind the limited data set, we can reach the following conclusions: (1) Using both Rayleigh and Love waves to calculate a  $M_s$  chosen by either manual or spectral methods gives no improvement in the reduction of scatter about the mean value line over  $M_s$  measured from the vertical Rayleigh; (2) Using three or more VLPE stations to average radiation pattern effects produced no reduction in scatter. At this point, it is felt that the scatter about the mean value line can only be reduced by accounting for path effects (i. e., multipathing). Future studies will determine if, in fact, this can be accomplished.



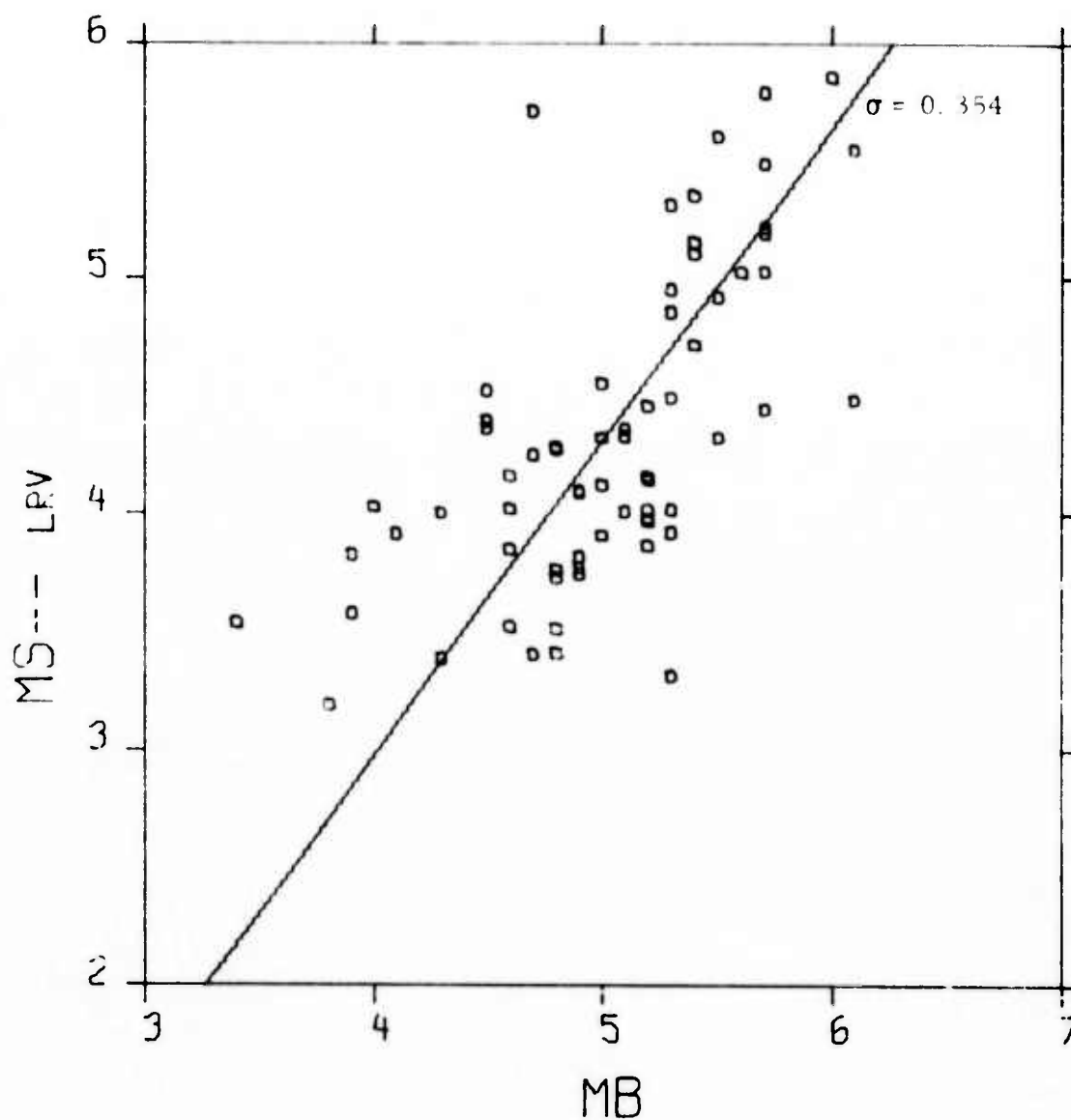


FIGURE II-11a

$M_S - m_b$  FOR EURASIAN EVENTS RECORDED AT THREE OR MORE  
VLPE STATIONS (1972, 1973) -  $M_B$  CALCULATED USING  
VERTICAL RAYLEIGH COMPONENT ONLY

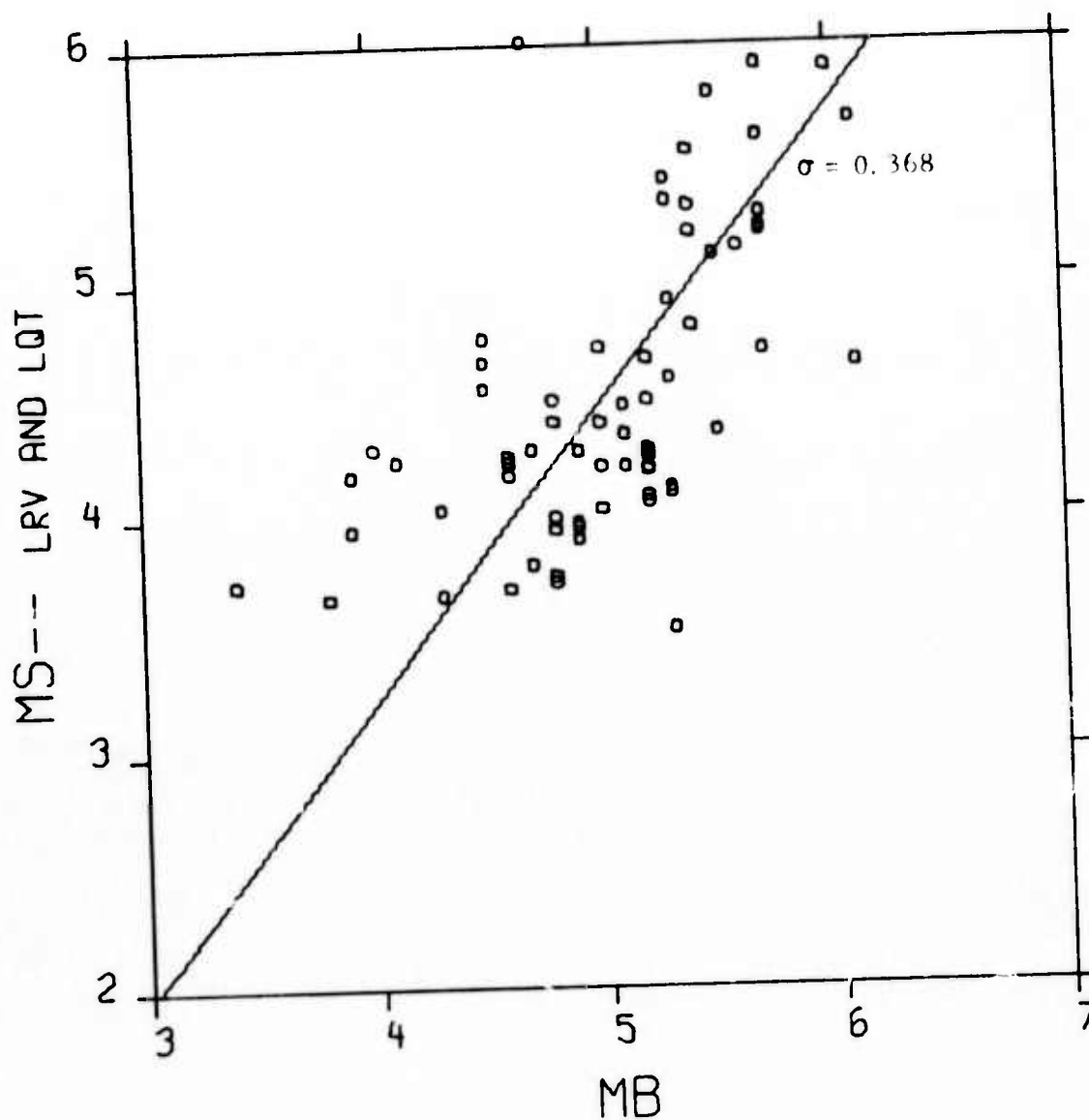


FIGURE II-11b

$M_s - m_b$  FOR EURASIAN EVENTS RECORDED AT THREE OR MORE  
VLPE STATIONS (1972, 1973) -  $M_s$  CALCULATED USING  
RAYLEIGH AND LOVE WAVE COMPONENTS

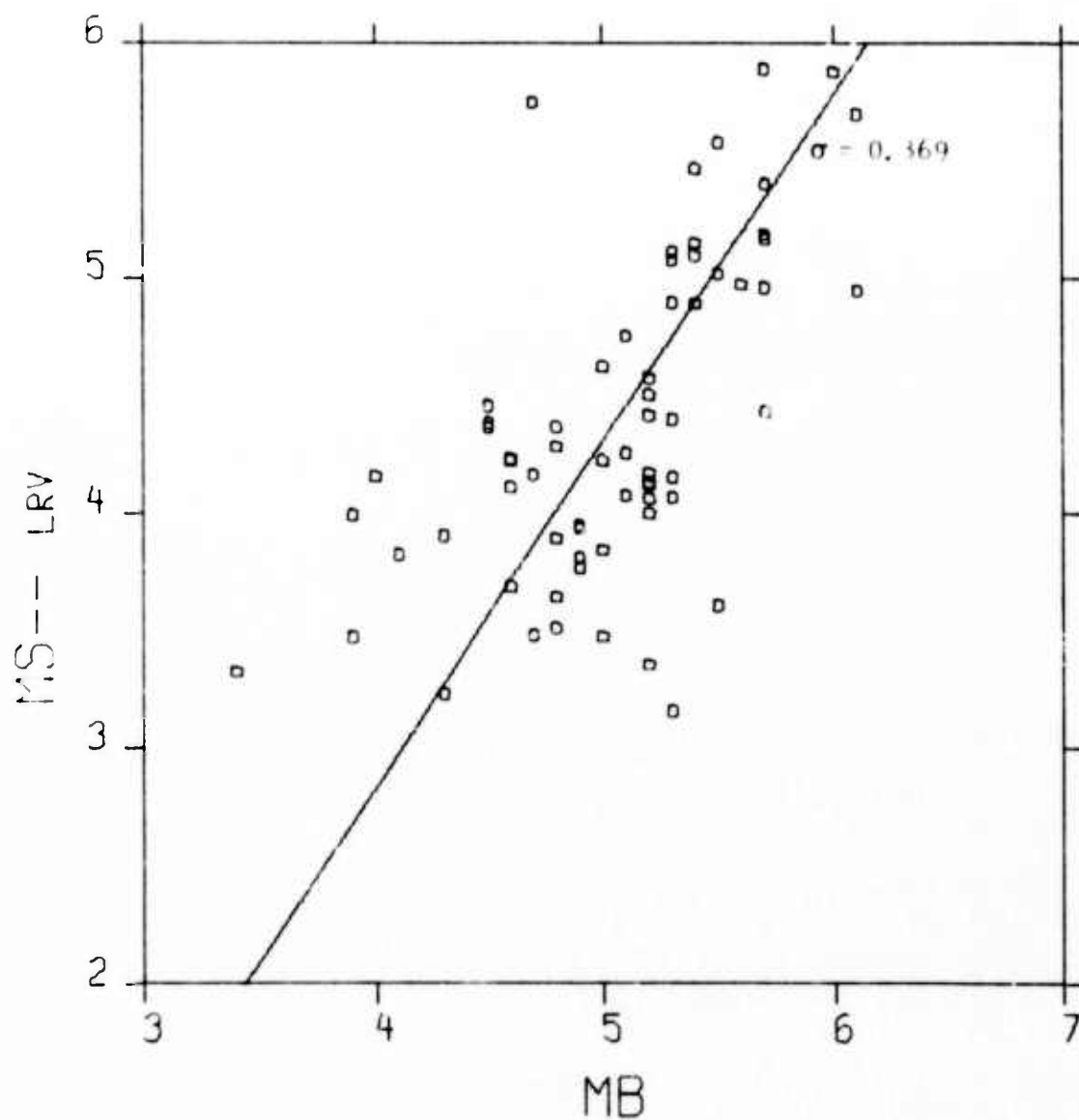


FIGURE II-12a

$M_S - m_b$  FOR EURASIAN EVENTS RECORDED AT THREE OR MORE  
VLPE STATIONS (1972, 1973) -  $M_B$  CALCULATED USING  
VERTICAL RAYLEIGH SPECTRAL MEASUREMENT ( $T = 20$  sec)

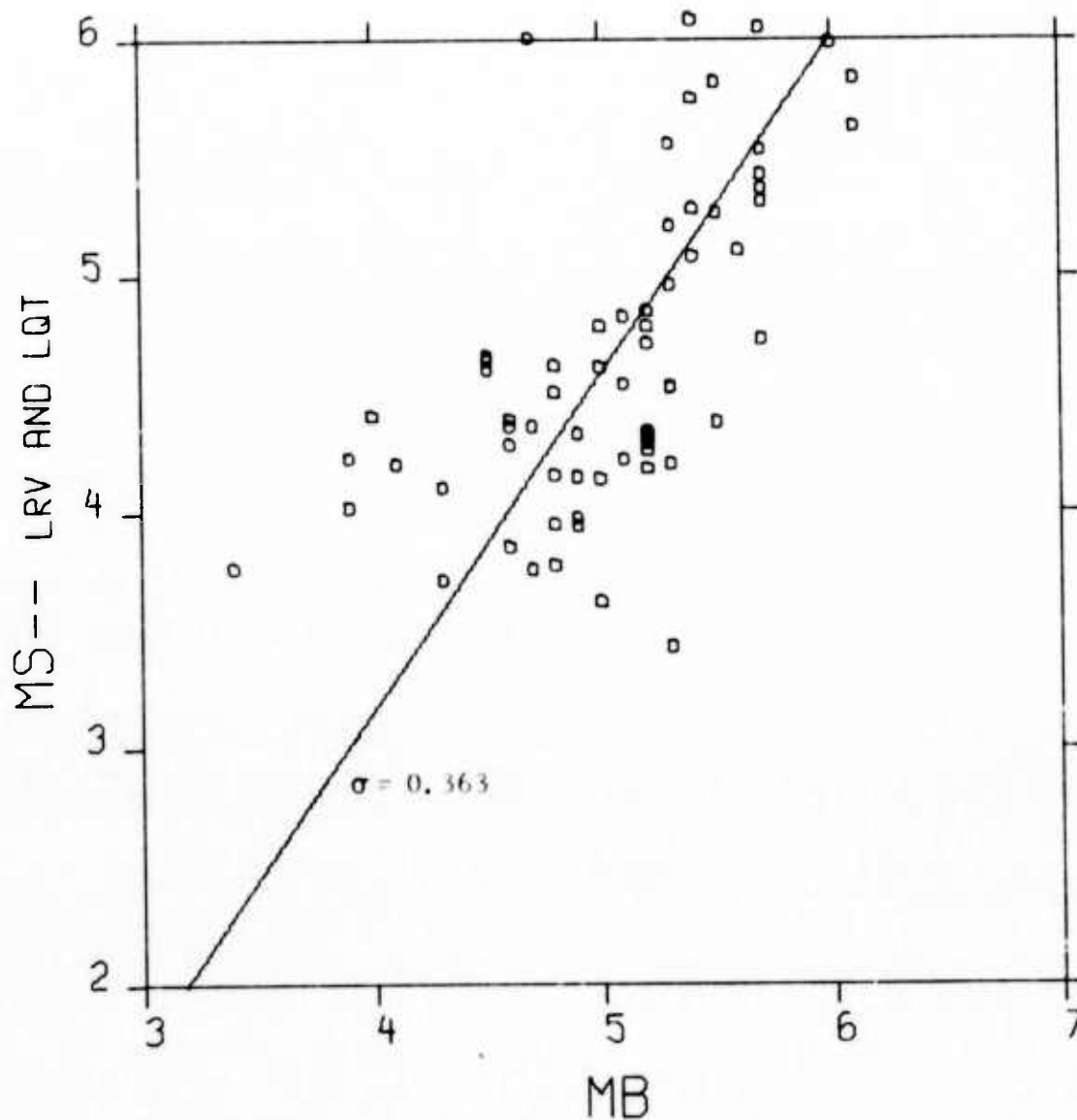


FIGURE II-12b

$M_s - m_b$  FOR EURASIAN EVENTS RECORDED AT THREE OR MORE  
VLPE STATIONS (1972, 1973) -  $M_s$  CALCULATED USING  
RAYLEIGH AND LOVE WAVE SPECTRAL  
MEASUREMENT ( $T = 20$  sec)

## E. CONCLUSIONS

Several tasks have been initiated in our study of far-field spectra for source characteristics. De-multipathing procedures have been implemented on the PDP-15 interactive graphics system. This software will facilitate the analysis of large suites of events from regions of interest. Three-dimensional computer plots of double couple source spectra have been produced, and will be used in an exhaustive analysis of far-field spectral characteristics as a function of source configuration. Particular interest will be directed toward the study of spectral holes, spectral levels, and spectral nodes as a function of the source parameters.

Finally, we briefly discussed two discriminants,  $LQ/LR$  amplitude ratios and  $M_s - m_b$ . It was found that theoretical  $LQ/LR$  ratios for earthquakes at 30 seconds period was greater than 1 for focal depths of  $h = 5$ , 30, and 50 kilometers. For the  $M_s - m_b$  discriminant, we attempted to reduce the scatter about the mean value line of earthquakes by making a uniform set of measurements (all at  $T = 20$  sec), and by minimizing radiation pattern effects (using both Rayleigh and Love wave amplitudes to calculate  $M_s$ , and obtaining  $M_s$  from several stations). Neither of these approaches reduced the scatter, leading us to the conclusion that path effects (multipathing) could have a significant effect on  $M_s$  measurements. Future studies will be concerned with this problem.

### SECTION III

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